Stephanie L. van den Boogaard

Supporting the Negotiated Selection of a Pareto Optimal Solution

A design study on the added value of a decision aiding approach with Simulation-Based Many-Objective Optimisation

Master Thesis – Delft University of Technology
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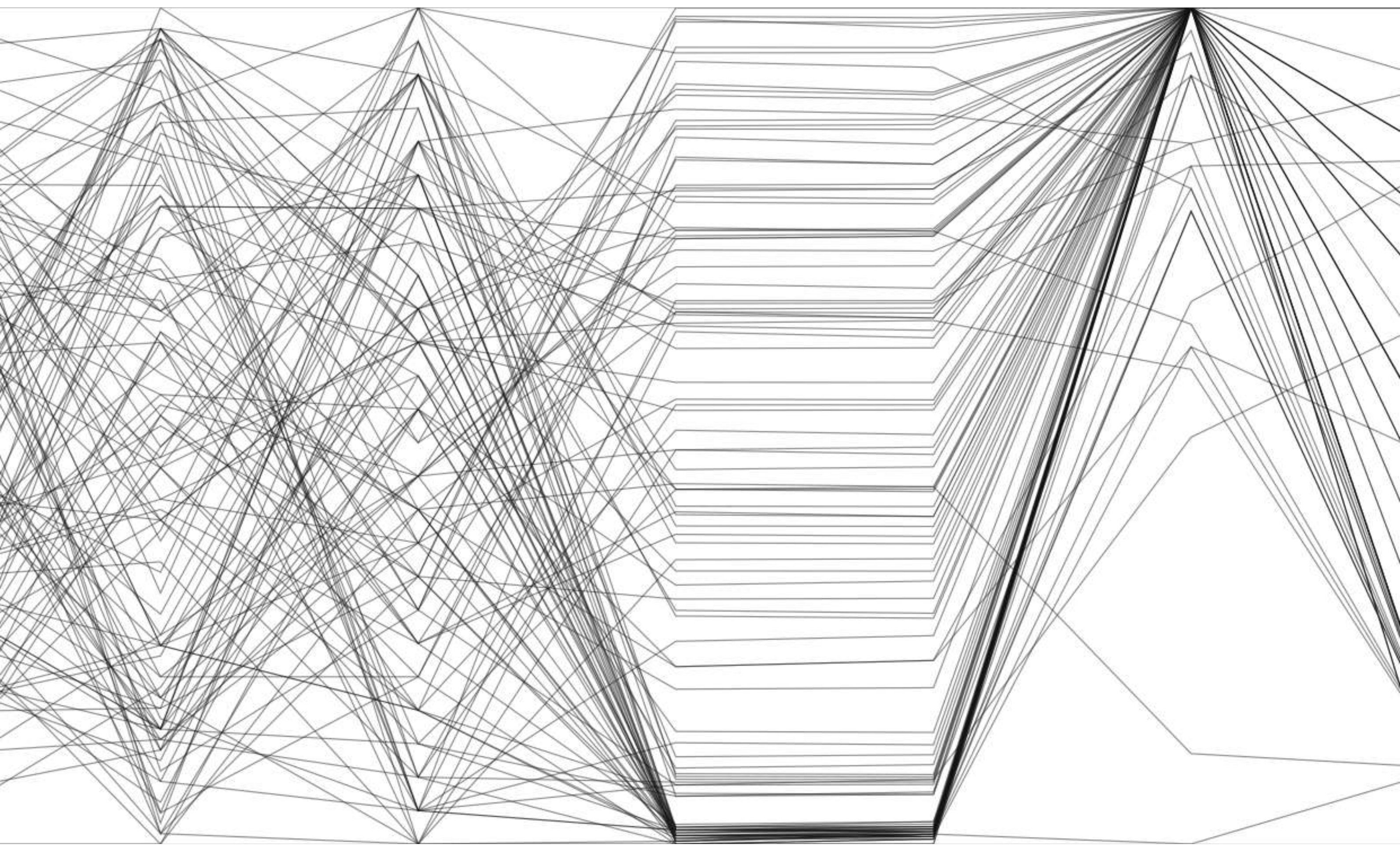

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DELFT UNIVERSITY OF TECHNOLOGY

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by

Stephanie L. van den Boogaard

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Acknowledgements

A few days before the final deadline of my thesis something happened which made clear how short life can be. This made me realise how grateful I am to share my graduation ceremony with the people who are most important to me. With my graduation my life as a student ends, and a new life as young professional starts. My graduation is a big step in my life, and I hope many will follow which I can share with all my friends and family.

Even though it might sound cliché, I am truly proud to present to you my final piece of work for my Masters Systems Engineering, Policy Analysis & Management. To me, this thesis is the crown on all the education I had so far. I always enjoyed my education and I always searched for new challenges. And in my graduation project I definitely found a challenge. The challenge of formulating a realistic, valuable and precise scientific research plan; the challenge of combining theory with practise at my internship at ING; the challenge of asking time and participation of persons who had a busy agenda; and finally, the challenge of keeping up my motivation over the past six months while doing this project on my own.

Even though I had my ups and downs, looking back I see mostly ups. I enjoyed searching for an interesting and valuable topic and the enthusiasm of the persons at ING about the practical results of my research. I could never have achieved all of this without several persons who helped me during my project. First, many thanks to Jan Kwakkel, without whom I never could have made the connection between Many-Objective Optimisation and the simulation model. This was, kind of, the most crucial part of my research. Thanks to Haiko van der Voort for the inspiring and open discussions about the 'human part' of my research. And of course, many thanks to Alexander Verbraeck, for pushing me to take that extra step. Many thanks also to Carmen for keeping me on track for my practical contribution as well. And of course, many thanks to Colien, my ING buddy, for helping me to find my way at ING and for always being there when I wanted to talk or needed help.

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I am proud of myself. On to the next step!

Summary

Within organisations there tends to be an insatiable wish to improve business processes (Adesola and Baines, 2005). Improvements vary from creating a faster process, a higher quality product or service, a reduction in cost, and so on. Urged by increasing competitive pressure, a thorough process improvement program is vital for the survival of many organisations. Several different process improvement methods have been developed over time, such as Lean Six Sigma and Modelling and Simulation (Adams et al., 1999; Bhuiyan and Baghel, 2006).

Recently, an innovative approach to support improvement of business processes has gained the attention of scientists and practitioners: Many-Objective Optimisation (MOO) with a posteriori decision analysis. This method aims to simultaneously optimise multiple, sometimes conflicting, objectives using algorithms inspired by the processes of natural evolution (Chand and Wagner, 2015). The result of a Many-Objective Optimisation is a set of Pareto optimal solutions, which is a set of possible solutions with different trade-offs between the conflicting objectives (Branke et al., 2008). Where this brings several benefits, such as the opportunity to involve multiple stakeholder perspectives in the optimisation since no prioritisation in the objectives has to be made beforehand, this also complicates the application. All Pareto optimal solutions in the solution set are considered equally desirable from a mathematical viewpoint (Branke et al., 2008). From a practical viewpoint, some Pareto optimal solutions might be more desirable due to an underlying preference in the trade-offs between the objectives. Picking a solution from the set of presented Pareto optimal solutions is an important step within the application process of MOO, and it requires the presence of one or more decision makers to negotiate and decide upon the most desired trade-off (Tsoukiàs, 2008). This research focuses on Simulation-Based MOO.

Research Problem

Even though MOO with a posteriori decision analysis is a very promising method, the application remains challenging. Due to an information overload, the decision makers should be supported in a certain way to be able to make a decision. Furthermore, the problem formulation influences the output of the optimisation, and this problem formulation can be seen as another step where the decision makers need to be involved Franssen (2005). How to support the decision making process with the use of MOO is scarcely addressed explicitly in literature. Furthermore, most literature addresses the application of MOO on strategic policy problems, such as water allocation (Labadie, 2004). Such problems can be characterised as ill-structured, where this research sees business process improvement problems as semi-structured problems (Scheubrein and Zionts, 2006). The problem structure influences how the decision making process should be supported (Newell, 1969), but in current literature the difference between using MOO on a semi-structured problem or ill-structured problem is not made clear. It can be concluded that there is a lack of guidance on how to support decision makers to select a business process

improvement possibility, given the results from a Many-Objective Optimisation. The objective of this research is to develop an approach which increases awareness of decision makers about business process improvement possibilities, to support the selection of a solution. Based on this the main research question can be answered, which is formulated as follows: *What is the added value of a decision aiding approach with Simulation-Based Many Objective Optimisation for a semi-structured process improvement problem?*

This research does not aim to develop a method which itself provides one optimal or most satisfying solution after a Multi-Criteria Decision Making process. It aims to contribute to the awareness of the decision makers about business process improvement possibilities, which will enable them to make a better decision within the selection of a solution (Endsley, 1995). This is known as the concept of *Decision Aiding* (Tsoukiàs, 2007). Resulting from the research objective, the expected deliverable of this research is a stepwise decision aiding approach which can be used by analysts who use Many-Objective Optimisation. The decision aiding approach will be evaluated in a business context at ING Operational Services on behalf of the Operational Excellence Department. The practical deliverable for ING is knowledge about Many-Objective Optimisation, a business process improvement method they currently do not use, and a complementing stepwise approach explaining how to apply this in their business process improvement projects.

Research Methods

The research objective asks for the design of a decision aiding approach. Therefore, it is decided to use the design science framework of Hevner (2007). The design of the decision aiding approach consists out of three parts: the design of a constructive decision aiding process, a design of the visualisation which will be used in the decision aiding approach, and the design of the Many-Objective Optimisation model. The main research methods used in this research are: (1) a literature research, (2) simulation optimisation (SO) and (3) a case study. In addition to the creation of the design itself, demonstrating and evaluation the application of the design is an important part of this research. The evaluation is twofold: evaluate the working of the designed approach, and identify improvement possibilities. Based on this, conclusions can be drawn on the added value of the approach.

Design Artefact I - A Constructive Decision Aiding Process

The first part of the design is a constructive decision aiding process. This process can be seen as stepwise guidance for the analyst executing the decision aiding approach. The process starts off with creating an overview of the problem, identifying stakeholders and formulating a problem overview together with all involved stakeholders. Next, the SO model is designed and validated. The results of this model are discussed during a negotiation session, which is the final step of this process. The process allows for many iterations for the problem formulation and model creation, since this is needed to be able to deal with the semi-structured character of the problem.

Design Artefact II - The Simulation Optimisation Model

The second artefact, the SO model, combines a simulation model with an optimisation algorithm. For both cases, a Discrete Event Simulation model is designed and the optimisation analysis is done using the ϵ-NSGA-II algorithm. The creation of the model is approached differently than when only the model is only used by the analyst himself. The decision makers are closely involved during the creation and multiple iterations can take place to adjust the model to a changing problem formulation. The SO model results in a Pareto optimal solution set. Even though the two case studies both used a DES model, the decision aiding approach is also suitable for other type of models, such as system dynamics, as long as they can be connected with a Many-Objective Evolutionary Algorithm.

Design Artefact III - An Interactive Visualisation

The third part of the design is the graph which is used to visualise the results of the optimisation. The designed visualisation is a type of parallel coordinate plot which is horizontally oriented. The most left axes represent the different solution variables, the other axes represent the objectives. The user can interact with the graph and manipulate the view by selecting specific ranges of interest on the different axes and view the corresponding solutions.

Integrating the Three Artefacts in the Decision Aiding Approach

The three artefacts together form the decision aiding approach. Within the approach, the decision aiding process can be seen as the stepwise guide during which the other two artefacts are created and used. The three elements all need to be in place for the decision aiding approach to function properly and they strengthen each other. The decision aiding approach combines the 'soft' perspective of constructive decision aiding with the 'hard' perspective of SO and it this way brings substance to the process while respecting the complexity of the semi-structured problem.

Main Findings

The decision aiding approach is applied on two cases at ING Bank and evaluated. To conclude upon the main research question five aspects are identified where the decision aiding approach is of added value:

1. The decision aiding approach results only in Pareto optimal solutions

2. The decision aiding approach increases the (self-rated) awareness of the decision makers

3. The decision aiding approach can result in faster convergence of the preferences of the decision makers

4. The decision aiding approach results in support and ownership for the selected solution
5. The decision aiding approach stimulates trust in the results of the SO model

Scientific & Practical Contribution
Often, decision support is very much focused on the construction of the evaluation model, the formal model which is constructed by the analyst which aims to evaluate potential solutions and provides information about the problem (Tsoukiàs, 2007). Other approaches to decision aiding focus merely on problem structuring and formulation, supposing that formulating a problem is equivalent to solving the problem. The designed decision aiding approach incorporates both aspects and explicitly presents a possible way to apply simulation optimisation in a process improvement problem for analysts. It is seen that such a decision aiding approach has substantive added value, such as resulting in optimal solutions, and strategic value in a decision making process, such as leading to a faster convergence towards a solution.

The decision aiding approach can function as a stepwise guide for the analysts of ING, or analysts within other companies, when tackling a semi-structured process improvement problem. It is seen that approaching a process improvement problem as semi-structured instead of well-structured can be valuable. It can lead to an increase in support and ownership for the selected solution, and to a solution which better solves the problem.

Research Limitations
In this research, it was not possible to compare the decision which was made with the decision aiding approach to the decision which would have been taken without the decision aiding approach. Therefore, it cannot be stated that the decision aiding approach leads to the selection of a better solution than without the decision aiding approach. In addition, since the implementation of the solution was beyond the scope of this research, the performance of the process with the selected solution cannot be compared to the performance before the decision aiding approach. A final limitation of this research is that the performance of the MOEA is not taken into account.

Suggestions for Future Research
Five suggestions for future research are presented: (1) to execute the decision aiding approach while running another decision aiding project using a classical simulation study, or other method which is normally used by the decision makers, and compare the results of both groups, (2) to extend the decision aiding approach with an implementation phase, (3) to apply the decision aiding approach with the possibility to use multiple problem formulations (4) further improve the visualisation by adjusting the labels or by adding a new interaction possibilities to show solutions which are 'close' to the selected preferences, and (5) to apply the designed decision aiding approach to different types of organisations in comparable domains, and/or to comparable type of organisations in different domains.

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Abbreviations

ASA	Average Speed of Answer
CLT	Customer Loyalty Team
CSV	Comma-Separated Values
DDB	Department of Distresses & Bankruptcies
DES	Discrete Event Simulation
DM	Decision Maker
EMO	Evolutionary Multi-Objective Optimisation
FTE	Full Time Equivalent
KPI	Key Performance Indicator
MCDM	Multiple Criteria Decision Making
MOEA	Many-Objective Evolutionary Algorithm
MOO	Many-Objective Optimisation
ING	Internationale Nederlanden Groep
OM	Operational Management
SA	Situation Awareness
SDE	Service Desk Executors
SO	Simulation Optimisation
TITO	Today In = Today Out

"Live as if you were to die tomorrow.
Learn as if you were to live forever."

- Mahatma Gandhi

1 | Introduction

Within organisations there seems to be an insatiable wish to improve business processes (Adesola and Baines, 2005). Improvements vary from creating a faster process, a higher quality product or service, a reduction in cost, and so on. Urged by increasing competitive pressure, a thorough process improvement program is vital for the survival of many organisations. Several different process improvement methods have been developed over time, such as Lean Six Sigma and Modelling and Simulation (Adams et al., 1999; Bhuiyan and Baghel, 2006).

1.1 Evolutionary Multi-Objective Optimisation

Recently, an innovative approach to support improvement of business processes has gained the attention of scientists and practitioners: Evolutionary Multi-Objective Optimisation (EMO). This method aims to simultaneously optimise multiple, sometimes conflicting, objectives using algorithms inspired by the processes of natural evolution (Chand and Wagner, 2015). An example of such conflicting objectives can be *high quality of product X* and *low production cost of product X*. Often, a *higher quality* requires better, more expensive materials, which makes the production of product X *more expensive*. In other words, high quality has a negative impact on low cost, and vice versa. When both high quality and low price are considered important objectives, some kind of trade-off needs to be made between those objectives.

When more than three objectives are included in the optimisation, one talks about Evolutionary *Many*-Objective Optimisation. During the World Congress on Computational Intelligence in 2006, EMO was assigned to be one of the fastest growing fields of research and application among all computational intelligence topics. It brings together researchers and practitioners with different backgrounds, such as computer scientists, mathematicians, economists and engineers aiming to better solve complicated problem-solving tasks (Deb, 2010). In literature, EMO is often referred to as Multi-Objective or Many-Objective Optimisation (MOO). Therefore, this thesis will also use the term MOO.

The algorithms used in a Many-Objective Optimisation study often embed simulation models to capture the output performance given certain input specifications (April et al., 2003; Kasprzyk et al., 2015). This possibility allows for the avoidance of simplifying assumptions to come to an explicit optimisation function that is often required for classical optimisation studies (Labadie, 2004). This approach is known as Simulation-Based Many-Objective Optimisation, or Simulation Optimisation (SO) in short (Fu et al., 2005). This research focuses specifically on Simulation-Based Many-Objective Optimisation.

1.1.1 Benefits and a Complication of Using MOO

The result of a Many-Objective Optimisation is a set of Pareto optimal solutions, which is a set of possible solutions with different trade-offs between the conflicting objectives (Branke et al., 2008). A solution is Pareto optimal when it *"cannot be improved in a given objective without degrading its performance in another objective"* (Woodruff et al., 2013, p203). Some of the benefits of Many-Objective Optimisation are perceived to be (1) the ability to identify Pareto optimal solutions, instead of using trial and error to experiment with different options or discussing solutions which are not possible to achieve, which makes process improvement more efficient (Uriarte et al., 2015), (2) the opportunity to involve multiple stakeholder perspectives in the optimisation, since no prioritisation in the objectives has to be made beforehand (Kasprzyk et al., 2015) and (3) the possibility to gain insights in the trade-offs between multiple objectives, which makes decision making more transparent (Deb, 2010). These advantages make MOO especially relevant for problems where several conflicting objectives exist and where it is unclear how those objectives influence each other.

A complication of the use of MOO arises from the very same fact which brings the benefits: MOO results in a set of Pareto optimal solutions, instead of pointing out one 'most optimal solution'. From a mathematical viewpoint, all Pareto optimal solutions are considered equally desirable (Branke et al., 2008). From a practical viewpoint, some Pareto optimal solutions might be more desirable due to an underlying preference in the trade-offs between the objectives. Picking a solution from the set of presented Pareto optimal solutions can be seen as an important step within the decision making process of a MOO exercise. It requires the presence of one or more decision makers to negotiate and decide upon the most desired trade-off. When there are multiple stakeholders with conflicting interests involved, the selection of a solution might not be straightforward due to a different underlying preference regarding the trade-offs (Tsoukiàs, 2008). For example, a product engineer might value *high quality* over *low price*, but a salesman might value *low price* over *high quality*.

An overview of the decision making process complementing a MOO exercise is visualised in Figure 1.1. Selecting a solution from the Pareto optimal solution set can be seen as the second decision making step. This step is related to the first step of decision making; the problem formulation. Important decisions in the problem formulation are the definition and selection of objectives, defining constraints and requirements and determining the level of aggregation of the objectives. As Franssen (2005) showed, the problem formulation influences the results of

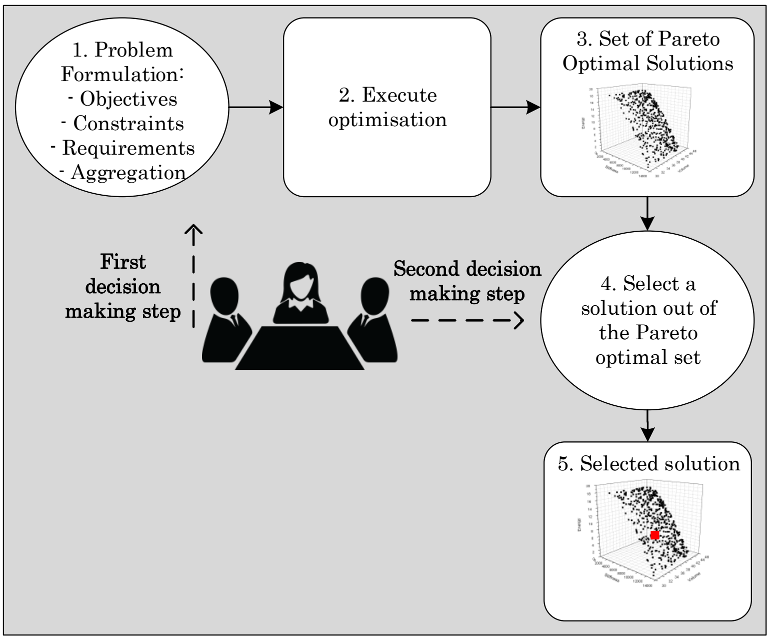


FIGURE 1.1: Schematic view of decision making process, partially based on Deb (2010)

a MOO. How the problem formulation step in the decision making process can influence the outcome of an optimisation can be illustrated by the following example. When one asks the question: *Do you prefer high quality and high cost, or low quality and low cost of product X?* the choice is limited to product X. Potential other products which can influence the preference of a decision maker are excluded from the decision. Maybe another product is available which has the same quality as product X, but a lower price. When one asks the question: *Do you prefer Product X or Product Y?* the answer is not limited to Product X, and the decision maker can take other objectives he/she might have, such as the appearance of the product, into account in the decision. In other words, the first decision making step influences the second decision making step, hence the two cannot be seen as unrelated steps.

The second and final decision making step can be seen as a very crucial step, since in the end the organisation is often searching for only one solution to implement. Nevertheless, literature does not agree upon a method how this final decision making step should be approached.

1.2 Research Problem & Research Objective

The decision making process resulting from the use of Many-Objective Optimisation has been underexposed for many years within the field of MOO research, where researchers mainly focused on the development and improvement of algorithms (Deb, 2010; Chaudhuri and Deb, 2010). Another field of research, Multiple Criteria Decision Making (MCDM), has developed well established methods for decision makers to address multi-objective problems (Purshouse et al., 2014). This field mainly emphasised the use of preference models which lead to a single preferred optimal solution. Attempts to blend MOO and MCDM resulted in three different approaches for decision analysis (Purshouse et al., 2014):

1. *A priori* decision analysis; the preferences of the decision maker(s) are incorporated in one aggregated function prior to the optimisation execution
2. *Interactive* decision analysis; the preferences of the decision maker(s) are progressively incorporated during the optimisation process
3. *A posteriori* decision analysis; the preferences of the decision maker(s) are not incorporated in the optimisation execution and a decision should be made afterwards out of the set of optimal solutions

1.2.1 A Priori Decision Analysis

When a priori decision analysis is used, the two decision making steps are integrated into one step prior to the optimisation execution. In an ideal situation, where the preferences of the decision maker(s) can be captured in a mathematical function, this would be the most effective option (Purshouse et al., 2014). However, this is rarely the case in practise. The different decision makers can be seen as different stakeholders with diverse interests. To come to a mathematical function which captures all preferences of the decision makers, weights must be assigned to the objectives to indicate their relative importance. This requires the resulting function to be *"an internally consistent measure of stakeholders' decision preferences"* (Kasprzyk et al., 2015, p1). Often, it is not possible to construct such an internally consistent function due to conflicting objectives and conflicting interests of stakeholders. This problem is known as the Impossibility Theorem, or Arrow's Paradox, named after Nobel Prize winner Kenneth Arrow (1950).

If it would be possible to formulate an internally consistent optimisation function, this would not necessarily lead to the best solution. Franssen (2005) and Kasprzyk et al. (2015) showed that using an aggregated optimisation function limits the ability of an optimisation algorithm to come up with diverse solutions, and in this way biases the solution set towards certain objectives in ways that cannot be known beforehand by the decision makers. Formulating an internally consistent optimisation function requires to use some kind of aggregation of the objectives within the function (Kasprzyk et al., 2015). This suggests that using an a priori decision making approach can exclude a part of the solution space resulting in a decision which is biased towards certain objectives. More diversity in the solution space is believed to results in a better solution, so it is undesired to have a biased solution space (De Bruijn et al., 2010).

1.2.2 Interactive Decision Analysis

The interactive approach enables the decision makers to explore and learn about the set of possible solutions and to adjust their preferences during the optimisation. Compared to a priori methods, the necessary preference information is less complicated (Jaszkiewicz, 2007). Several different procedures have been developed for an interactive approach. Jaszkiewicz and Branke (2008), for example, developed an algorithm which uses a range of preference functions compatible with multiple preferences. This reduces the set of Pareto optimal solutions produced by the optimisation. Greco et al. (2008) introduced decision rules to cut off less interesting solutions from the Pareto set.

A disadvantage of the interactive approach is that the decision makers need to be involved intensively during the optimisation process, which makes it very time consuming in a business context (Purshouse et al., 2014). Furthermore, the method does help decision makers to exclude certain solutions, but does not help them to select the best one.

1.2.3 A Posteriori Decision Analysis

The a posteriori approach can be seen as the approach which will have the most diverse set of solutions as output, since the full range of Pareto optimal solutions are included in the set due to no prioritisation during the optimisation. This type of approach produces a large number of solutions with many dimensions, which enriches the decision making since many options can be considered, and increases the chance of the presence of a solution which is acceptable to all stakeholders. On the other hand, the presence of a large amount of solutions can cause difficulties for decision makers to analyse such solution sets and select one option as best solution (Fu et al., 2005; Jaszkiewicz and Branke, 2008). Such a selection process often is a negotiation between different stakeholders, each with its own interests and desired trade-offs.

It should be mentioned that the problem formulation, the first decision making step, still influences the output of an a posteriori approach; a different problem formulation could lead to a different solution set.

It is believed that a diverse set of solutions enriches the decision making process and will lead to a higher chance of finding a satisficing solution (De Bruijn et al., 2010). Besides, variety enables the decision makers to become aware of the possible solutions. It can be concluded that when executing a MOO the a posteriori method can be of great value since it allows for more variety than the a priori and the interactive approach.

1.2.4 Using Visualisation to Manage Complexity

The a priori and interactive decision making approach aim to reduce the complexity of a decision for the decision maker by presenting a smaller solution set. As stated before, this can lead to less variety, which is not desired. The a posteriori approach does not reduce the complexity of the decision in such a way, enabling for more variety in the decision making process. For a relatively small problem the solution set may contain already thousands of solutions (Jaszkiewicz and Branke, 2008). However, human cognitive capacity is finite and it is seen that decision makers are having trouble to find meaning in large and complex data sets due to an information overload (Woodruff et al., 2013). Hence, a way to make it less complex for decision makers to explore and understand large and complex data sets is vital for the decision making process when the a posteriori approach is used. Visualisations can be used to enable decision makers to grasp large and complex data sets and several studies demonstrate the value of visualisation in Many-Objective Optimisation (Kasprzyk et al., 2015; Kollat and Reed, 2007a; Woodruff et al., 2013). Interactive visualisation techniques can be used to explore trade-offs between different objectives and in this way support the search to a satisficing solution. However, visualising many-dimensional spaces is not straightforward and remains a challenge (He and Yen, 2016; Kollat and Reed, 2007a).

1.2.5 Knowledge Gap: Supporting Decision Making

Even though the a posteriori decision making approach is a very promising method, the application remains challenging. Due to an information overload, the decision makers should be supported in a certain way to be able to make a decision. MOO could help the decision makers to become more aware of trade-offs between objectives, and to discover differences between different stakeholder perspectives (Kollat and Reed, 2007a), however, only when this is supported during the decision making. In addition, the influence of the problem formulation on the output is an important factor, which is often not considered during the decision making. A comprehensive approach to support decision making by enabling the decision makers to explore the possible solutions and trade-offs between objectives through MOO is scarcely addressed in literature. Instead, research is often focused on a specific part of decision making and MOO, i.e. the influence of the problem formulation, or visualisation of the output, etc. It is conjectured that MOO practitioners do probably combine these elements implicitly or subconsciously when using MOO, however it is scarcely addressed explicitly in literature. Addressing a coherent approach in an explicit way makes it easier to reproduce and can therefore be valuable. It can potentially lead to an easier decision making process and more effective application of MOO.

Research on applying MOO often is focused on strategic policy problems, such as problems related to water allocation and environmental systems, see for example Kollat et al. (2011), Kasprzyk et al. (2013) and Labadie (2004). MOO can also be applied to more operational business processes, such as manufacturing designs or hospitals processes, see for example Fleming et al. (2005), Kollat and Reed (2007a) and Thieke et al. (2007). Problems in these two contexts differ, which might have implications for the use of MOO and how the decision making should be supported. Problems in a strategic policy context can be characterised as ill-structured problems. Ill-structured problems are situations where it is not clear what exactly the problem is, what solutions are possible and which criteria can be used for the selection of a solution (Keen and Morton, 1978; Simon, 1973). Often, multiple stakeholders are involved, each with their own knowledge, stakes and preferences (De Bruijn, 2008). Problems in an operational context often are perceived to be well-structured problems. A problem can be characterised as well-structured when the problem can be clearly demarcated, the solution space is finite and there are definite criteria to judge the solutions upon (Gorry and Morton, 1971; Simon, 1973). However, it is believed that problems in an operational context where MOO can be of use are not completely well-structured. Often there are conflicting views on which criteria to use to judge the potential solution upon. Furthermore, often the solution space is not completely clear. Approaching such a problem as well structured does not respect the complexity of the problem and might results in a solution which does not solve the true problem of which does not have sufficient support. Therefore, this research uses the term semi-structured problem to characterise the problems dealt with in this research.

A semi-structured problem is a problem which has some aspects of a well-structured problem, such as clear system boundaries, whereas others aspects are ill-structured, such as the criteria on which the potential solutions are judged (Keen and Morton, 1978; Scheubrein and Zionts, 2006). It is believed that by approaching the problem as semi-structured, the selected solution might better solve the problem, since there might be more support from the different stakeholders and since the problem and solutions are formulated based on the multiple existing perspectives. There is a relationship between the problem structure and how the problem solving can be approached (Newell, 1969). A well-structured problem can for example be solved by replacing human decision makers by a computer model, but for a semi-structured or ill-structured problem this is not possible. By approaching the problem as semi-structured or ill-structured, selecting the best solution is not straightforward anymore, and decision makers must be involved to do this selection. Keen and Morton (1978) state that therefore decision support is especially relevant for semi-structured and ill-structured problems. But in current literature, the distinction between semi-structured and ill-structured is not made clear in connection to the decision support which is necessary when MOO is used.

1.2.6 Problem Statement

The knowledge gap described above leads to the following problem statement:

There is a lack of guidance on how to support decision makers to select a solution, given the results from a Many-Objective Optimisation.

Even though this problem arises with some of the interactive decision making approaches as well, this research focuses on the a posteriori approach. This demarcation results from the fact that a posteriori MOOs are considered to have the largest potential to lead to a diverse set of solutions (Franssen, 2005; Kasprzyk et al., 2015), which is seen as a requirement for an effective decision making process. This research concentrates on (Simulation-Based) Many-Objective Optimisation problems, since the need for decision support is more present here than in a Multi-Objective Optimisation due to more complex problems and output. Of special interest are situations where not only conflicting objectives exist, but also conflicting stakeholder interests, since in this case it will probably not be possible to formulate an internally consistent value function, which excludes an a priori and many of the interactive approaches, and it makes the decision making less straightforward. This research is focused on the application of MOO in an operational business process improvement project, where the problem can be seen as semi-structured.

This research does not aim to develop a method which itself provides one optimal or most satisfying solution after a Multi-Criteria Decision Making process. It aims to contribute to the awareness of the decision makers about the relations between different objectives and solutions, which will enable them to select a solution. This is known as the concept of *Decision Aiding* (Tsoukiàs, 2007) or *Decision Support*. In this research a constructive perspective on decision aiding is selected. Chapter 3 will provide more background on the concept of decision aiding and will motivate the choice for the constructive perspective. An overview of how the concepts decision making, decision aiding and Many-Objective Optimisation relate to each other is given in Figure 1.2.

1.2.7 Research Objective and Deliverable

The research objective follows from the problem statement and is formulated as follows:

> *To develop an approach which increases awareness of decision makers about business process improvement possibilities, to support the selection of a solution.*

Resulting from the research objective stated above, the expected deliverable of this research is a stepwise decision aiding approach which can be used by analysts who use Many-Objective Optimisation. This approach guides the analyst in his/her support of the decision makers with the selection of a Pareto optimal solution which is the result of a Many-Objective Optimisation.

The first part of the objective for the decision aiding approach is to increase the awareness of the decision makers about business process improvement possibilities. This awareness can be seen as a form of situation awareness (SA) (Endsley, 1995). In this case, this awareness involves the possible solutions (or design alternatives) to improve a business process, the different

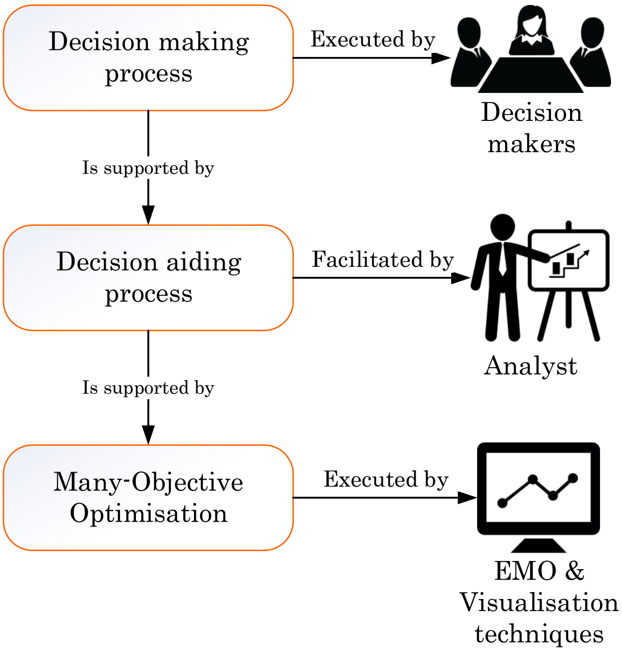


FIGURE 1.2: The relation between Decision Making, Decision Aiding and Many-Objective Optimisation

conflicting objectives and the trade-offs amongst them, and the preferences of other decision makers regarding that trade-offs. It is presumed that SA is necessary for humans to execute a task effectively (Endsley and Garland, 2000). It is expected that an increase in SA leads to a more thorough understanding of decision makers about the possible solutions and the effect on the objectives, meaning that the decision makers are more aware of the possibilities which exist and the consequences of their decisions. This awareness leads to a better decision compared to a decision which is made when the decision makers are less aware of the situation (Endsley, 1995). Since it is desired that the use of the decision aiding approach leads to the selection of a solution which increases the performance compared to the current situation, it is desired that the approach increases the situation awareness which results in a decision which increases the performance. Therefore, the increase in awareness is seen as objective of this research.

The second part of the objective of the decision aiding process is to enable the decision makers to select a solution. This objective is successfully reached when the selected solution is one of the Pareto optimal solutions which resulted from the Many-Objective Optimisation and all decision makers accept the selection of this solution. It is assumed that all solutions which result from the optimisation exercise are feasible solutions, provided that the models and data underlying the optimisation are validated. In this way the risk to select a solution which is 'negotiated nonsense', a solution which results from a negotiation but is not feasible or implementable since it is a little bit of everything, is mitigated. It is hard to say whether the selected solution is the best or most satisfying solution for the problem of the decision makers. Due to the complexity of the problems dealt with in a Many-Objective Optimisation, the rationality of the decision makers is bounded, which makes it hard to state whether a solution is most satisfying or not (Simon, 1955). According to Simon (1955) the selected solution will be some form of a 'satisficing solution' for the decision makers, meaning the first identified solution which satisfies all constraints of the decision makers.

The two objectives which are described above are the main focus of the decision aiding approach. The first objective, increasing the awareness about process improvement possibilities, requires variety in the decision aiding process. Variety allows the decision makers to become aware about new possible solutions and the ideas and values of other stakeholders (De Bruijn et al., 2010). To ensure a large variety, the a posteriori decision analysis is used. The second objective, selecting a solution, requires the presence of an overview of possible solutions and their effects on the objectives, being some kind of simplification of the complexity of the problem (De Bruijn et al., 2010). To create this overview, a visualisation of the MOO output is used. These two objectives tend to be a paradox: on the one hand variety is necessary to be able to increase the awareness, on the other complexity must be reduced to make it possible to select a solution. This paradox can be seen during the decision aiding approach; the beginning will mainly focus on stimulating variety, where the end will move from variety to selecting one solution using an overview of the possibilities. This is visualised in Figure 1.3.

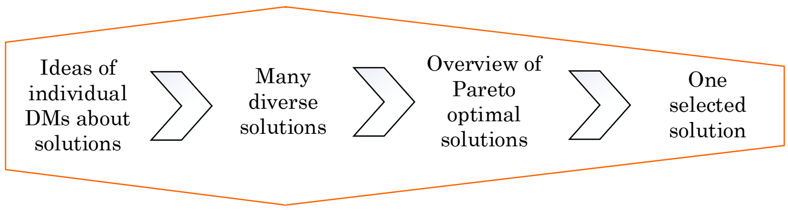


Figure 1.3: From variety to selection

The decision aiding approach is evaluated at ING Operational Services on behalf of the Operational Excellence Department. The practical deliverable for ING is knowledge about Many-Objective Optimisation, a business process improvement method they currently do not use and a complementing stepwise approach how to apply this in their business process improvement projects.

1.3 Research Questions

Following from the problem statement and the research objective, this research is concerned with the design of a decision aiding approach which uses Simulation-Based Many-Objective Optimisation. This decision aiding approach aims to support a group of decision makers to make a decision by increasing their awareness about process improvement possibilities. This approach is designed specifically for semi-structured process improvement problems. It is assumed that such problems concentrate on improving a business process by changing certain variables in the process, based on the performance on certain performance objectives. In addition to developing the decision aiding approach, applying and evaluating the approach is considered useful to determine the value of the approach. This leads to the following main research question:

What is the added value of a decision aiding approach with Simulation-Based Many-Objective Optimisation for a semi-structured process improvement problem?

The added value can be split in two parts: substantive value and strategic value. Substantive value relates to value regarding the content of the improvement problem, for example the quality of the solution. Strategic value relates to value for the decision making process, such as more support for the selected solution. To answer the main question several sub questions are proposed. The answers to the sub questions together form the knowledge basis for the design of the approach and answering the main research question. The sub questions of this research are formulated as follows:

1. *Which activities and artefacts make up a constructive decision aiding process?*
   To be able to design a decision aiding approach, knowledge should be gained about what such a decision aiding approach incorporates.

   Deliverable: Overview of functions and artefacts of a decision aiding approach (Ch. 3)

2. *How does a constructive decision aiding approach look which uses SO and a visualisation to support decision makers in a business process improvement problem?*
   This sub question combines the knowledge from the previous sub questions in a design of a constructive decision aiding approach.

   Deliverable: Integrated design consisting out of a constructive decision aiding process, SO model and visualisation (Ch. 3, 4, 5 and 6)

3. *How can the value of the decision aiding approach be evaluated?*
   The designed approach will be applied on two real-life cases at ING Operational Services and evaluated in order to identify the impact and possibilities for improvement. It is however not straightforward how the value of the decision aiding approach can be evaluated.

   Deliverable: Evaluation setup (Ch. 2)

4. *What is the efficacy of the designed visualisation in increasing the awareness of decision makers about business process improvement possibilities?*
   Visualisation is seen as an important means to manage the complexity related to the output of a Many-Objective Optimisation. It is however not straightforward how the results should be visualised to support the decision maker(s) and what the efficacy of the visualisation is.

   Deliverable: Visualisation design and evaluation (Ch. 5 and 8)

5. *What are the strengths and weaknesses of the designed decision aiding approach in supporting decision making on operational business process improvements?*

The two case studies are used to identify strengths and weaknesses of the designed decision aiding approach. The weaknesses of the approach studied to identify possibilities for improvement.

Deliverable: Overview of strengths, weaknesses and improvement possibilities for the decision aiding approach (Ch. 7, 8 and 9)

1.4 Societal and Scientific Relevance

Decision making is an everyday activity for almost every person (Tsoukiàs, 2007). Often these decisions are fairly simple, such as the decision to order a cup of coffee or a cup of tea in a restaurant. However, on an organisational or inter-organisational level the decisions become harder. A question such as *"How should we change our customer contact process in order to increase customer satisfaction and to lower the cost?"* is not answered easily. First, it is often unknown in what way the process can be improved, let alone that one knows which way is best. Second, the objectives, low cost and high customer satisfaction, tend to be conflicting, and it is often unsure how they exactly influence each other. These types of questions and related decision making problems are common practice for organisations. MOO could contribute to solving this type of questions, however, only when the decision making is supported. This research contributes to the support of the decision making, and in this way could potentially contribute to more effective decision making in organisations.

Besides the societal relevance of the proposed research, it is relevant from a scientific perspective as well. It addresses a key research gap in current literature, namely the scarce availability of guidance on how to aid a MOO decision making process in an operational business context, and it complements the current available methods of Many-Objective Optimisation.

1.5 Thesis Outline

This thesis presents a design study on a decision aiding approach to support the selection of a solution from the results of a Many-Objective Optimisation. This chapter introduced the topic of Many-Objective Optimisation and identified a current knowledge gap in scientific research. Following on this, Chapter 2 elaborates on the research methods which are used to study this knowledge gap. Chapter 3 goes into depth on the concept of decision aiding and presents the design of a decision aiding process. This design is complemented with a design for a simulation optimisation model in Chapter 4 and the visualisation of the optimisation output in Chapter 5. Chapter 6 explains how the three design elements are integrated in the decision aiding approach and Chapter 7 demonstrates the use of the approach in two cases. Chapter 8 presents the results of the evaluation of the decision aiding approach. A discussion about the results is presented in Chapter 9. This thesis ends in Chapter 10 with the main conclusions of this research and possibilities for future research.

2 | Research Framework & Methods

Before going into depth on the content of decision aiding and Many-Objective Optimisation, this chapter discusses the research framework which is used to structure this research. In addition, the research methods which are used during this research are elucidated.

2.1 Research Framework: Design Science

The main research question as posed in Section 1.3 asks for a design study on a decision aiding approach. To structure this research and to be able to effectively answer the research questions, the design science research framework of Hevner (2007) is selected. This framework originates from the field of Information Systems, but is used in various fields related to engineering and design (Hevner, 2007). The primary aim of design science research is to improve an environment, the setting to which the design is applied, which is in this case an improvement in the way decision makers are aided to make a decision (Simon, 1996). The design science framework uses three different cycles. The 'rigor cycle' relates the design to the knowledge base of scientific theories, and experience and expertise which is available in the research project. The 'relevance cycle' relates the design to the environment in which the design will be applied and evaluated. The 'design cycle' iterates between creating and evaluating the design artefacts until a satisfactory design is created, based on the insights from the rigor and relevance cycles (Simon, 1996).

The perspective on design as taken by Hevner (2007) includes both the organisational context in which the design is applied and the technical and theoretical background. The resulting design will be based on both these contexts and can be called a socio-technical design. This perspective on design fits well with the objective of this research, since this includes both technical optimisation methods as an organisational context in which the decision makers operate. Figure 2.1 presents an overview of the design science framework and its three cycles.

2.1.1 The Knowledge Base

The knowledge base can be seen as the underlying foundation for the artefacts to be designed. Without proper knowledge of existing designs and the most recent theories and methods, the creation of an innovative and valuable design will be hard (Hevner, 2007). In this research the

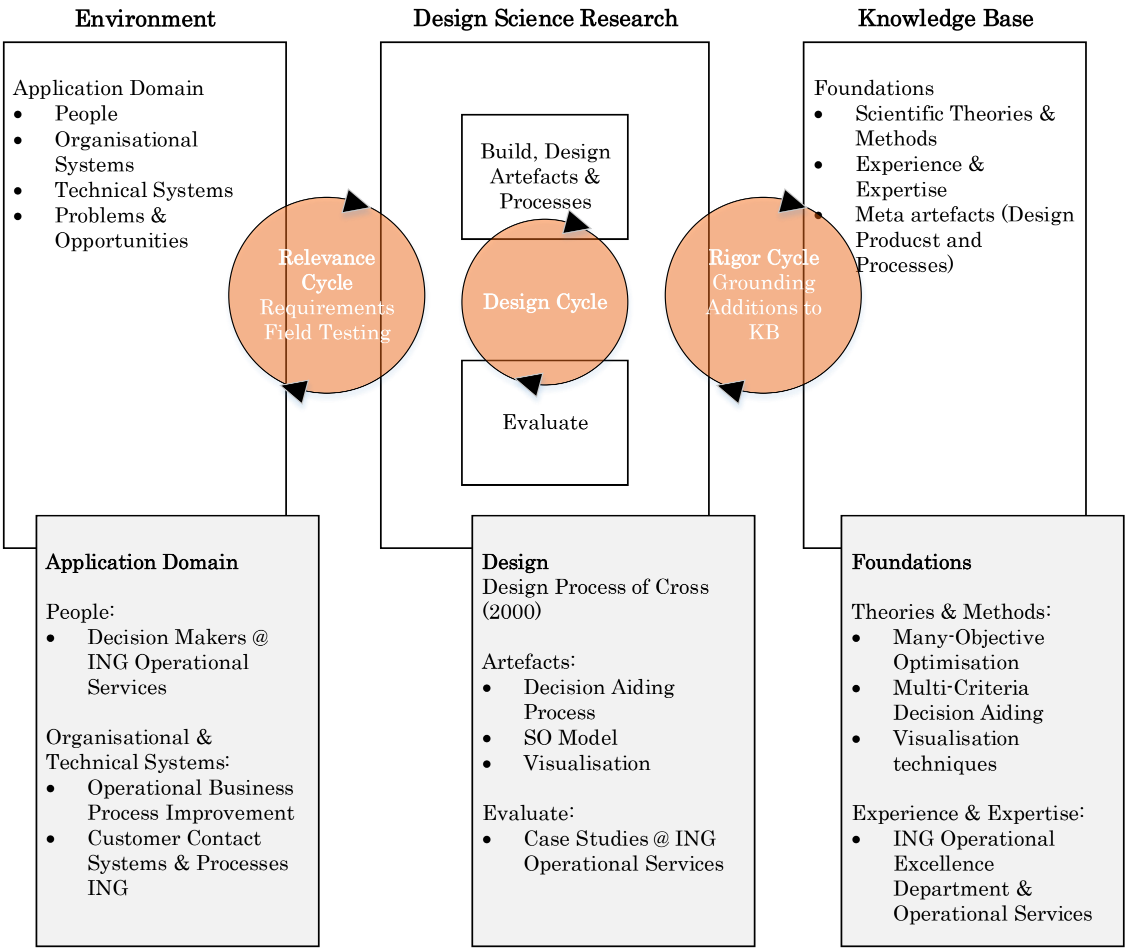


FIGURE 2.1: Applied Design Science Framework based on (Hevner, 2007)

knowledge base will be formed by scientific literature on Many-Objective Optimisation, Multi-Criteria Decision Aiding, methods and techniques for visualising complex data and the experience and expertise available at ING Operational Excellence Department and ING Operational Services.

2.1.2 The Environment

The context for which the decision aiding approach is designed is the improvement of a business process for which decision makers decide upon the way to improve the business process. The approach is evaluated in two case studies at ING Bank, which implies that the design is adjusted to the characteristics of such an organisation.

ING is a global financial institution which offers banking services through its operating company ING Bank. ING Bank operates in more than 40 countries and has over 33 million customers worldwide. In The Netherlands ING Bank is one of the leading banks serving 8,7 million customers and companies. The strategy of ING aims to create *"a differentiating customer experience, enabled by simplifying and streamlining our organisation, further striving for operational excellence, enhancing the performance culture within our company and expanding our lending capabilities"* (ING, 2016b). One of the departments within ING Bank is the department of Operational Excellence Consulting (Blackbelt). This department is dedicated to one of the four pillars of INGs strategy: continuous improvement of operational excellence. It executes projects at different departments of ING in order to improve the business processes of the departments (ING, 2016a). Using the characterisation of Mintzberg (1993) the Blackbelt can be seen as part of the techno structure of the organisation ING Bank. As part of a Centre of Expertise their main objective is to improve business processes both for customers and for ING by analysing and solving problems based on facts and qualitative data. Often their projects are focused on departments of ING Operational Services, which are part of the Operating Core of ING Bank (Mintzberg, 1993). These departments execute the core work of the bank, such as opening and terminating bank accounts, helping customers who have troubles with their credit cards or debit cards, etc.

In 2015 ING completely reorganised their organisational structure and its way of working to be able to quickly respond to changing customer requirements and technological innovations (ING, 2016c). Currently most of the organisation has adopted the agile methodology, resulting in self-managing, autonomous units with end-to-end responsibility for a specific customer-focused process. This organisational structure is important to consider when designing the decision aiding approach, since the approach should fit this agile way of working. The decision aiding approach will be evaluated at two departments of ING Operational Services, which implies that most decision makers whom are involved in the process are part of the Operating Core of ING.

2.1.3 The Design Science Research

Designing the decision aiding approach can be seen as the heart of the design study. To come to a complete and sound design, the structured design process of Cross (2000) is followed. There are many different design processes which can be followed. Most of them are focused on designing a physical product, such as a car, or focused on designing a system, such as an IT system. The four-stage design process as proposed by Cross (2000) is expected to work not only for a product, but also for a process, since it is a quite general approach to designing an artefact. Cross (2000) constructed a simple descriptive model of the design process, which is visualised in Figure 2.2, based on the most essential activities the designer executes. The process starts with the *exploration* of the design problem at hand. In the next phase, the *generation*, the design is composed. The design is evaluated based on the original goals and constraints in the *evaluation* phase. In this research, the design is evaluated using two case studies at ING Operational

Services. The end-point of the process is the *communication* of a design, which can be seen as one of the most crucial phases for the usability of the design, since only a proper communication enables others to use the designed artefact. More information considering this design process can be found in Cross (2000).

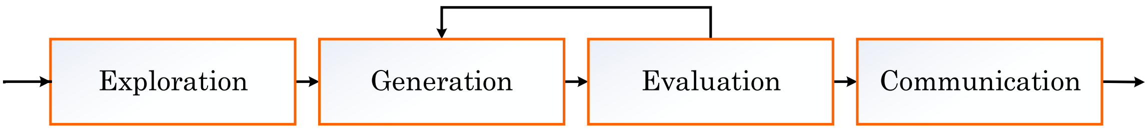


FIGURE 2.2: The Design Process of Cross (2000)

Designing the decision aiding approach consist out of three different parts: a design of a constructive decision aiding process, the design of the simulation optimisation model and the design of the visualisation which will be used to visualise the output of the optimisation model. These three designs all contribute to the design of the decision aiding approach. This is visualised in Figure 2.3

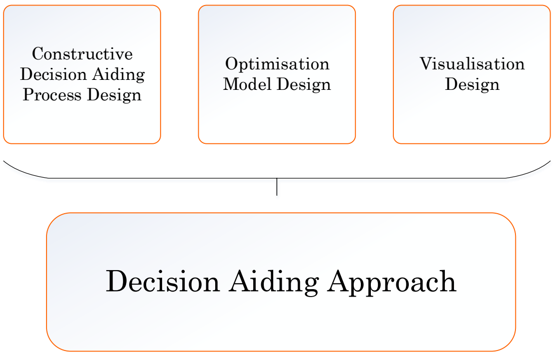


FIGURE 2.3: Three different designs within the decision aiding approach

2.2 Research Methods

The research framework and the research questions guide us towards research methods which are necessary to answer these questions. The main research methods used in this research are: (1) a literature research, (2) simulation optimisation (3) a case study.

2.2.1 Literature Research

This research started off with a literature research to identify a knowledge gap in the current use of Many-Objective Optimisation and its scientific and societal relevance. The next step is to conduct a literature research to constructive decision aiding methods. This will fill the knowledge base of the research framework and answer the first research question of this thesis. This knowledge is combined with the know-how on Many-Objective Optimisation to come to a decision aiding process adapted to the characteristics of MOO.

Furthermore, examples of visualisations of the output of Many-Objective Optimisation are explored and other best practise visualisation techniques are studied. This forms the basis for the design of the visualisation. In addition to this, a quick literature research will be conducted to identify the most suitable Many-Objective Optimisation Algorithm (called a MOEA, Many-Objective Evolutionary Algorithm). *"MOEAs are a population-based search technique that use a process based on natural selection to evolve solutions that have good performance with respect to quantitative objectives"* (Kasprzyk et al., 2015). To be able to select an algorithm, several comparison studies are investigated, such as Chand and Wagner (2015); Hadka and Reed (2012a); Purshouse and Fleming (2007).

The designed decision aiding process, the simulation optimisation model, and the designed visualisation together form the decision aiding approach. Research question two combines these three components and the working of this approach is demonstrated in two cases and evaluated based upon these two cases.

The evaluation of the decision aiding approach has two main components. First it is evaluated whether the decision aiding approach reaches its objective and its strengths and weaknesses are assessed in order to identify possibilities for improvement. Second, the design of the visualisation is evaluated on its efficacy. There is no standard method of evaluating a decision aiding approach or a visualisation. Therefore, a brief literature research in evaluating methods of situational awareness and in evaluating methods of visualisation designs is conducted to determine how the evaluation will be done. This answers research question three. Based on the outcome of the evaluation research question four and five can be answered.

2.2.2 Simulation-Based Many-Objective Optimisation

The algorithms used in a Many-Objective Optimisation study often embed simulation models to capture the output performance given certain input specifications (April et al., 2003; Kasprzyk et al., 2015). This possibility allows for the avoidance of simplifying assumptions to come to an explicit optimisation function that is often required for classical optimisation studies (Labadie, 2004). This approach is known as simulation optimisation (SO) (Fu et al., 2005). This approach incorporates two elements: a simulation model and an optimisation algorithm. Nowadays many types of commercial simulation software contain an optimisation package that can execute a search for optimal input values (April et al., 2003). However, often such packages are quite limited in choice of optimisation algorithms and specifications. Therefore it is decided connect a state-of-the-art MOEA to the simulation software specified for this research using python.

The type of simulation model which is used in this research is Discrete Event Simulation (DES), since this type of model fits best with the characteristics of the processes at ING which are the topic of the case study. However, the MOEA can be used with other type of simulation models as well. DES is a method which imitates the operation of real-world processes and systems over time by changing variables only at specific discrete points in time (Banks, 1999). DES is particularly suited to model customer service processes, such as queuing systems (Robinson et al., 2012). The customer contact processes of ING match these characteristics. Arena simulation software of Rockwell Automation is used to build the discrete event model. For more information about Arena, see arenasimulation.com.

2.2.3 Case Study

An important part of this research is to apply and evaluate the designed decision aiding approach. This is done by a case study. In this way the application of the designed decision aiding approach can be demonstrated and the working can be evaluated. Two cases are incorporated within this case study, where the first is exploratory the second one is used for validation purposes. The first case is used to explore the application of the designed approach and practical lessons learned are formulated about the applicability of the design. Based on these lessons, the decision aiding approach is slightly adapted. In the second case, the adapted version is applied. The second case is mainly seen as a validation that the approach can be used in multiple situations. Furthermore, after the second case a reflection is done upon the adjustments which were made after the first case, to see whether it improved the decision aiding approach.

Topic of both cases is a customer contact process at ING Operational Services. Improving such a customer contact process is not straightforward. Several objectives tend to be conflicting, such as 'a low waiting time on the phone for customers', 'a fast processing time of requests' and 'limited budget for personnel'. It is desired to gain insights in the trade-offs between those objectives in order to make a decision in which everyone is aware of the consequences. This need for information fits well with the possibilities of a Many-Objective Optimisation study. A detailed description of the two cases can be found in Chapter 7.

2.2.4 Evaluating the Decision Aiding Approach

Based on the two case studies the decision aiding approach is evaluated. Goal of the evaluation is twofold: evaluate the working of the designed approach, and identify improvement possibilities. To evaluate the working it is evaluated to what extent the decision aiding approach reaches its objective. The selection of a Pareto optimal solution can be seen as a hard criterion for reaching the objective. The increase in awareness is a means which will allow for a better decision. In addition, the efficacy of the visualisation is evaluated, since this is seen as a means to reach the objective. To identify improvement possibilities the match between the context and the decision aiding approach is evaluated. Furthermore, the participants are asked to provide general feedback about the strengths and weaknesses of the approach as they experienced it. An overview of the evaluation elements can be found in Figure 2.4. This sub section elaborates on the evaluation methods.

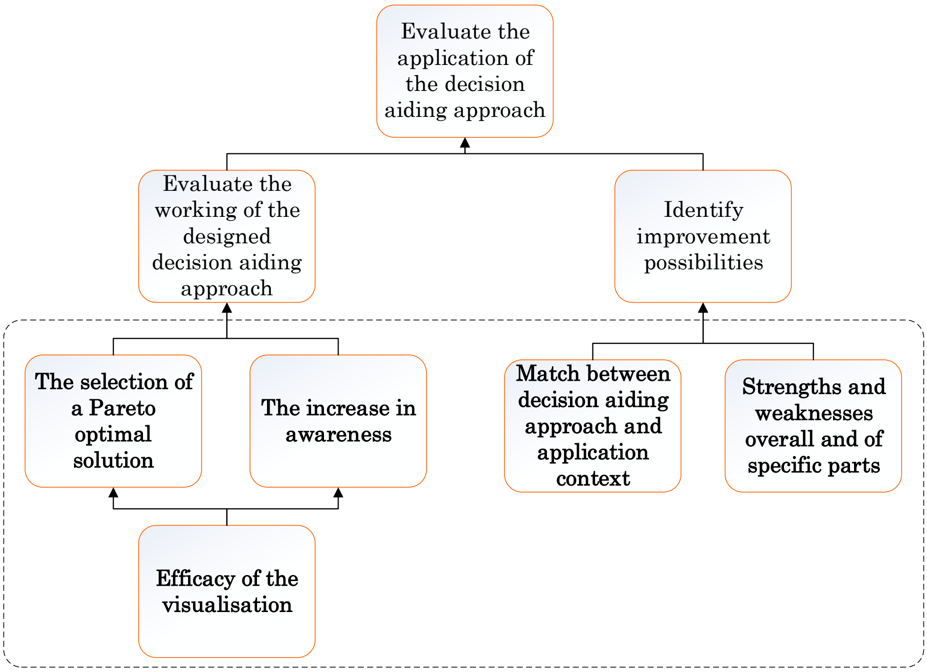


FIGURE 2.4: Evaluation elements

2.2.4.1 Did the Decision Aiding Approach Reach Its Objective?

The objective of the decision aiding approach, as explained in Section 1.2.7, contains two parts:

1. It aids the selection of a (Pareto optimal) solution
2. It increases the awareness of the decision makers about business process improvement possibilities

The first part of the objective can be evaluated in a straightforward manner; at the end of the decision aiding process it can be checked whether the decision makers could reach a decision about the selection of a solution. The evaluation of this part is therefore done based on answering two questions:

1. *Did the decision makers select a solution?*
2. *Is the selected solution one of the Pareto optimal solutions as provided by the results of a MOO?*

When both questions are answered with 'yes', this part of the objective is successfully reached. When one or both questions are answered by 'no', it is analysed why this is the case. This analysis is done during interviews with the decision makers which are held after the decision aiding process. During this interviews it is tried to find the causes for not selecting a (Pareto optimal) solution. An example of a cause can be that the decision makers did fundamentally disagreed about the trade-offs and none of the Pareto optimal solutions was acceptable for all parties. Another cause can be that the decision makers did not have confidence in the results of the MOO and therefore did not selected a solution. This lessons will be taken into account to further improve the decision aiding process.

The second part of the objective is less straightforward in its evaluation. In literature, different methods can be found to determine the situational awareness, all with their own strengths and weaknesses. In addition, these methods are often focused on tasks where there is only one decision maker and where response time is extremely important, such as in aviation, air traffic control and military command and control operations. The situation of the decision makers in the designed decision aiding approach is not fully comparable with such a dynamic and high pressure situation, mainly due to less time pressure and the fact that the decision makers do not necessarily share one perspective on what is best, so there is not a single right answer to many of the questions the decision makers have. Therefore, it is not possible to adopt one of the standard SA evaluation frameworks as evaluation method in this research. They are, however, used as an inspiration and foundation of the method developed in this research.

It is important to make explicit what is meant with an increase in awareness of the decision makers about business process improvement possibilities to be able to evaluate it. In literature different definitions of SA exist. This research uses the definition of Endsley (1995) which state that SA is a cognitive product of information-processing, meaning that situation awareness can be achieved when information is processed supported by cognitive functions. Cognition is a broad concept, and in literature multiple definitions exist, but in this case one can think of cognitive functions such as perception, recognition, reasoning, judgement and learning (Anderson, 2013). Endsley (1995) explains that SA can be seen as the main precursor to decision making, so a decision is made based on the perception of the decision maker of the current situation. A perfect SA does not necessarily lead to a perfect decision, however, little or limited SA probably does not lead to an increase in performance after the decision (Endsley, 1995).

Using the definition of Endsley (1995) SA comprehends three different levels; (1) the perception of data, (2) the comprehension of meaning and (3) projection on the near future. The first level is concerned with the information and knowledge the decision makers have. The second level goes beyond this by including how decision makers process this information and combine, interpret and judge it to give it a meaning. Level three, being the highest SA level, is concerned with the ability of the decision makers to project the consequences of their decision to the near future. For this research, the projection on the *near* future is less relevant, however, the projection on the future in general certainly is relevant. Being able to project the consequences of their decision on the future implies that the decision makers are aware of the effect of the chosen solution. So, for this research, the last level is adapted to 'projection on the future'. The evaluation is set up based on these three levels of SA. Four different aspects are identified which indicate the SA of the decision makers based on these three levels. An overview is presented in Figure 2.5.

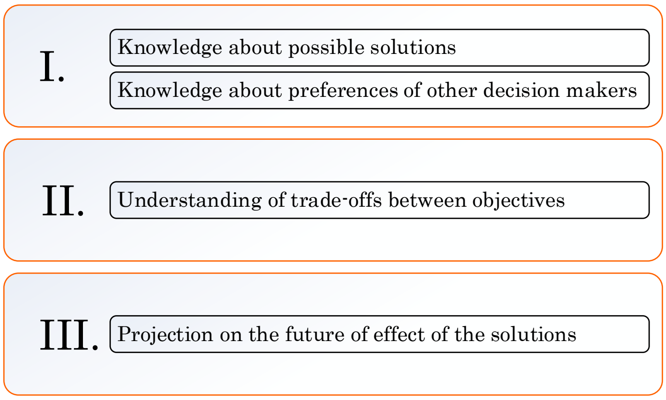


FIGURE 2.5: Awareness of business process improvement possibilities

Based on those four points, the evaluation is set up to identify an increase in awareness. The question whether the decision aiding approach did increase the awareness of the decision makers about business process improvement possibilities implies that the awareness of the decision makers should be measured multiple times to be able to compare. Ideally, the awareness should be measured at the start of the decision aiding process and subsequently after each step in the process, so it can be determined which steps did contribute to the increase in awareness and which did not. However, such an evaluation process requires a large time effort of all decision makers, and the risk exists that the decision makers start recognising the questions and routinely answer them in the way they also answered the questions earlier. Furthermore, measuring the situation awareness at the start of the decision aiding process is difficult, since it is unclear what the decision problem of the decision makers exactly is, and who is involved in the decision making. Thus, to evaluate the awareness, first some kind of problem situation should be clear. Therefore, it is decided to measure the awareness at three points during the process: the first time is after the problem structuring is determined, the second time is after the decision makers reviewed the results of the MOO individually, and the third time is after the decision makers collectively discussed the results in a negotiation session. The SA is measured using a short questionnaire, which can be found in Appendix A.

In literature multiple approaches can be found to measure SA; Stanton et al. (2013) reviews over thirty methods to do so which can be categorised in five different types. An overview and comparison of these different types can be found in Salmon et al. (2009). The way this evaluation is set up contains elements of the 'self-rating technique', and is complemented with the question to quantitatively write down their preferences on the different objectives and solutions. The decision is made to use a 'self-rating technique' for two reasons. First, the method does not require a lot of time from the decision makers and second, it does not disrupt the decision aiding approach. A risk of using a 'self-rating technique' is that decision makers might have troubles to recall the reasons for their decisions. Furthermore, the 'self-rating technique' provides us with results about how the decision makers felt about their awareness, not whether this corresponds with their true awareness, compared to others for example. The first risk is mitigated by asking the decision makers to fill in the questionnaire directly after the decision making task. The second risk is mitigated by measuring the awareness multiple times. Even though the rated awareness of the decision makers might not correspond directly to their true awareness, is does provide us with an indication whether the decision makers felt it did increase during the process. Furthermore, additional questions about the three levels of awareness are asked during the evaluation interviews (see more in Section 2.2.4.2).

The questionnaire allows to measure two different aspects: the preferences of the decision makers regarding the objectives and solutions over time, and their perceived awareness over time. By measuring the preferences of the decision makers multiple times during the process, changes in preferences become clear. The assumption is made that a change in preference indicates a change in the awareness of the decision makers (van Bueren, 2009). For example; the understanding of the decision maker about the trade-offs between objectives changed, and therefore his preference regarding those objectives changed. This information is used as an addition to the self-rated awareness of the decision makers. When a decision maker changed his/her preference, he/she is asked to explain the reasons behind this change based on a number of statements. When the decision maker did not change his/her preferences, he/she is asked to rate his/her awareness on several statements regarding the three levels of situation awareness as presented in Figure 2.5. In addition, in both situations it is asked how certain the decision makers are about their preferences and there is room for general comments.

One potential risk of the evaluation method is the possibility of the decision makers being framed by asking them to rate their preferences and awareness multiple times during the process. Especially letting the decision makers first individually inspect the results will have an influence on the negotiation between the decision makers later on, since the decision makers might already be aware that they have to change their preferences to be able to reach a decision. However, it is felt necessary to measure SA in different stages of the process to be able to isolate the effect of different elements of the decision aiding approach. Nevertheless, it is important to be aware of the possible framing effects.

2.2.4.2 Semi-Structured Evaluation Interviews

In addition to evaluating whether the decision aiding approach reaches its objective, the strengths and weaknesses of the approach and the match with the application context are evaluated. Based on this, improvement possibilities are identified which can be used as suggestions for further research on improvement of decision aiding with MOO. The strengths and weaknesses of the approach are evaluated using semi-structured interviews. The interviews focus on four different aspects:

1. The strengths and weaknesses of the overall and specific parts of the decision aiding process
2. The increase in situation awareness
3. The efficacy of the visualisation
4. The utility of the decision aiding approach in an operational business improvement project

Three different types of stakeholders are interviewed: the decision makers from the case studies, analysts of ING working on the same case, and analysts of ING not working on the particular case but familiar with the use of simulation studies. To each type of interviewee different questions are asked, due to their different experiences with the decision aiding approach and different expertise. The structure of the interview can be found in Appendix B. In this structure the four different aspects are explained in more detail.

2.2.4.3 Evaluating the Visualisation

Setting up an evaluation on the efficacy of the designed visualisations is not straightforward. As Munzner (2014) explains it is hard to determine how effective the proposed design is, since this can very much depend on the user. Furthermore, how do you argue that the design works better than other designs? The evaluation of the designed visualisation in this research in mainly concerned with the determination whether the visualisation did help the decision makers to select a solution and to increase the awareness on business improvement possibilities, and how this could be improved.

To structure the evaluation, the validation framework of Munzner (2009) is used. This framework identifies four different levels which require evaluation, see Figure 2.6. The first level, domain problem characterisation, is concerned with the main goal for the users of the visualisation. This is related to the ‘objective step’ of the design, which is discussed in Section 5.1. The second level, data/operation abstraction design, translates the objective to visualisation functions. This step is related to the ‘functions step’ of the design, as discussed in Section 5.3. The third level, the encoding/interaction technique design, is mainly concerned with selecting the best visualisation techniques to fulfil the functions. This corresponds to the design variables, as discussed in Section 5.4. The fourth and last layer, the algorithm design, focuses on the algorithm which carries out the visualisation techniques.

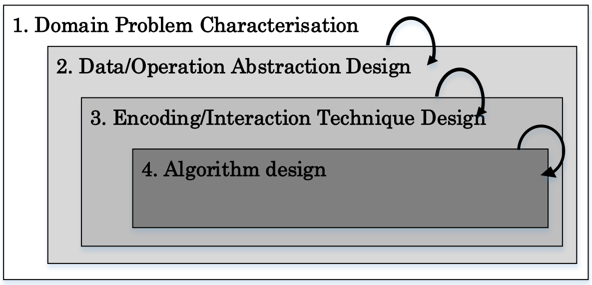


Figure 2.6: Four levels of visualisation creation (Munzner, 2009).

The evaluation which is used in this research focuses on the first three levels, since those have the largest influence on reaching the objective as stated in Section 5.1. Evaluating whether the algorithm which is designed is fast enough is out of scope of this research. An adjusted version of the evaluation framework of Munzner (2009) is presented in Figure 2.7. The framework is adjusted to match the scope of this research and is used to guide the evaluation of the proposed design.

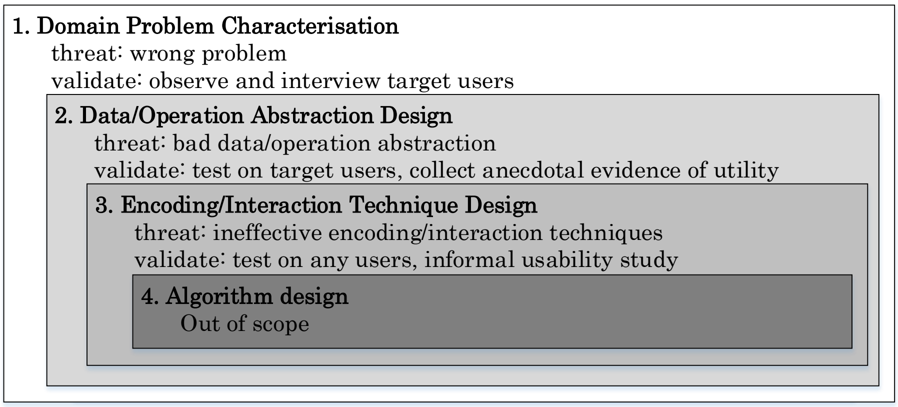


Figure 2.7: Framework used to evaluate the designed visualisation, based on (Munzner, 2009).

The evaluation of the proposed design contains four parts. First, the design is presented to several analysts of the ING Operational Excellence Department. They are asked to inspect the graph and test the interaction techniques, in order to identify unclear elements and errors. Furthermore, the graph is presented in black and white, to see whether it is still clear. This evaluation is mainly concerned with the third layer of the evaluation framework. Based on this evaluation, the design is improved. Second, the design is evaluated by using a role play with several persons at ING who are familiar with the type of business process. During this role play, each person has a different perspective on the problem and in this way different preferences on the objectives. They are asked to negotiate with each other based on the information provided by the visualisation and to select one solution in the end. This evaluation is used to validate the use of the visualisation to come to a decision in a multi-stakeholder environment, and is focused on layer one and two of the evaluation framework. Based on this evaluation, the design is again improved. The resulting design, which is presented in Chapter 5 is used during the case studies.

The third and fourth part of the evaluation are done during the case studies. The third part of the evaluation consist out of observations of the decision makers while using the visualisation. The observation mainly focuses on the second and third layer of the evaluation framework. The fourth part of the evaluation is done during the evaluation interviews, as discussed in Section 2.2.4.2. During these interviews questions are asked about the value of the graph to execute their task, the completeness of the information they saw in the graph, and the visual encoding and interaction functions. The analyst can also ask specific questions based on the observations. The interviews are thus concerned with layer one, two and three of the framework.

2.3 Chapter Summary

This chapter presented the research framework and main research methods which are used in this research. This research is structured by using the Design Science framework of Hevner (2007). The main research methods which are used in this research are literature research, simulation optimisation and a case study. The decision aiding approach is evaluated using a short questionnaire and semi-structured interviews. The next chapter will elaborate on the first part of the design: the constructive decision aiding process.

3 | The Constructive Decision Aiding Process

This chapter is designated to the design of the decision aiding process. First, the concept of Decision Aiding and the perspective taken in this research are explained. Subsequently the decision aiding process is designed and explained.

"Decision aiding is the activity of the person who, through the use of explicit but not necessarily completely formalized models, helps obtain elements of responses to the questions posed by a stakeholder of a decision process" (Roy, 1996, p10). Decision aiding is closely related to the field of decision support, which focuses on the role of computer models to support managerial judgement (Keen and Morton, 1978). To come to a (computer) model, the informal and ambiguous information about the problem must be translated to a formal problem formulation, such as an optimisation model. This requires a model of rationality. Several perspectives regarding this model of rationality can be found in decision aiding literature. The perspective taken will impact the approach taken in this research, since it influences what is included in the decision making process and ideas on how this can be aided. Tsoukiàs (2008) identifies four different perspectives to approach the translation:

1. ***Normative***: The normative perspective uses standard protocols to define a utility function a priori, which, when maximised, identifies the best solution. The protocols are based on the principles of rational decision maker(s). Preferences are assumed to be complete and consistent and independent of uncertainty. The model of rationality is not adapted to the specific problem, but external to the situation and imported into the decision process. The decision maker(s) should be aided to come to a decision following the rational protocols.

2. ***Descriptive***: The descriptive perspective takes into account that the behaviour of the decision maker(s) does not always respect the protocols used in a normative approach. It applies a model of rationality based on observations of other decision makers under similar circumstances. Again, the model of rationality is not adapted to the specific problem, but derived from similar situations and imported into the decision process.

3. ***Prescriptive***; The prescriptive perspective assumes that it is not possible to associate the decision maker(s) with an existing model of rationality, and searches for one within the specific problem situation. The issue is to identify the personal model of rationality of the decision maker(s) by unveiling the preferences of the decision maker(s). There is not necessarily one most optimal solution, but this is dependent on the local rationality of the decision maker(s).

4. ***Constructive***; The constructive perspective states that often the decision maker(s) is (are) not able to clearly define the problem situation, and in this way no objective model of rationality can be constructed. The first step of the decision aiding is to formulate a representation of the specific problem situation, together with the decision maker(s). Based on this representation a model is developed which will evaluate different possibilities. The whole decision aiding process can be seen as a learning process in which the decision maker(s) learn(s) about the problem situation. The problem structuring and formulation becomes equally important as trying to solve the problem.

Where the normative and descriptive mode might be the most applied approaches, these approaches are not always able to deal with complex problems, such as the ill-structured and semi-structured problems which often are topic of a MOO. A problem can embed two different types of complexity: (1) system complexity, and (2) political complexity (Mayer et al., 2005). The first type of complexity refers to the problem being complex due to many different interdependent variables, uncertainties and unknowns. The second type of complexity refers to complexity caused by the involvement of a network of stakeholders all with their own stakes and objectives. In the case where Many-Objective Optimisation is used, both types of complexity are often present. For example, multiple problem formulations are often possible since there are many unknowns. Furthermore, different involved stakeholders can disagree about the scope of the problem or the depth in which the problem is addressed, making it complicated to come to a consistent and unambiguous formulation of the problem situation (Franco and Montibeller, 2010). Besides, as discussed in Chapter 1, different stakeholders can have different, conflicting, values and interests, making it hard, or even impossible, to define one model of rationality for all stakeholders (Arrow, 1950; Tsoukiàs, 2007). Using a perspective which claims that a model of rationality can be defined and sees the problem as well-structured will probably come up with a solution which does not truly represent the problem of the decision makers since not all complexity is included in the problem formulation, or result in a solution which lacks support, since the solution is based on only one perspective. The constructive decision aiding approach takes this complexity into account, and is therefore selected as perspective in this research. The constructive perspective allows for iterative problem formulation and learning, which makes it possible to cope with the dynamics of changing perspectives and ideas about the problem. This perspective functions as a basis for the decision aiding approach to be designed. From now on, the person who supports the decision makers will be called the analyst. With the selection of the constructive perspective, the following assumptions are made:

- The problem which requires decision aiding is a complex problem;
- The decision makers actively try to come to a shared understanding of the problem and to select a solution;
- The involvement of key stakeholders as decision makers in the process of modelling and analysing will increase the chance that the decision makers will accept the chosen solution and commit to the implementation.

3.1 Objectives of a Constructive Decision Aiding Process

Cross (2000, p61) states that *"an important first step in designing [...] is to try to clarify the design objectives"*. The overarching objective of a decision aiding process is to facilitate one or more decision makers to come to a decision. This objective consists out of two parts, which are also described in Section 1.2.7; establishing an overview of the problem situation together with the decision makers, and learning about trade-offs between objectives and the effect of solutions. Learning, being one of the cognitive functions which can result in situation awareness, aims to increase the awareness of the decision makers regarding business process improvement possibilities.

The overview and the learning aspect influence each other. The first overview will be based on ideas of the decision makers, which together form the input for the evaluation model. The evaluation model is the model which is used to evaluate the different solutions, in this case this is the Many-Objective Optimisation model. Based on learning as a result from the creation of the evaluation model, or based on the output of the evaluation model, the overview of the problem can change. For example: an objective might be redefined or a constraint might be stretched. This concept is known in literature as double loop learning. The concept double loop learning entails the possibility to alter the goals or norms of the decision making process during the process itself, based on experience gained during the process (Argyris, 1976). The decision aiding process must incorporate this double loop learning possibility.

Two types of learning can be distinguished: (1) Substantive learning, the problem perceptions or perspectives of the decision makers change due to new available knowledge in the process, and (2) Strategic learning, the decision makers learn about the preferences of other decision makers and the inter-dependencies between the decision makers (van den Brink and Meijerink, 2006; De Bruijn et al., 2010). In the double loop learning cycle both types of learning can take place. It can for example be the case that an objective is redefined due to new available knowledge about the particular objective. It can also be the case that an objective is redefined because the decision makers learned that the definition is unacceptable for a particular decision maker, and that they therefore have to change the definition. So, where double loop learning mainly refers to an alteration in the goals or norms due to learning, the type of learning might explain what learning caused this alteration.

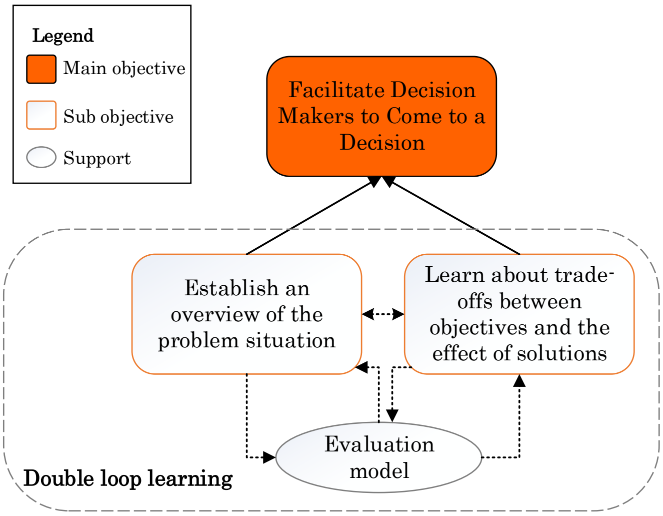


FIGURE 3.1: The objectives of a constructive decision aiding process

3.2 Requirements of a Constructive Decision Aiding Process

To use a constructive decision aiding process for supporting decision making with Many-Objective Optimisation in an organisational context, this process has to be adjusted to that specific characteristics. In other words, the designed decision aiding approach must be adjusted to the environment in which it is applied (Brown, 2015). In this case, it is applied at ING Operational Services. Sub section 2.1.2 elaborated on what kind of organisational context is present at ING operational services. The environment and the design are related via the relevance cycle, in which requirements for the design are deducted from the environment. Furthermore, the knowledge base imposes some theoretical requirements for a decision aiding approach. The requirements are established via the performance specification method of Cross (2000) and can be seen as the conditions the design should meet in order to be viable. To get a comprehensive set of requirements, the requirements are divided in three categories: (1) constraints, (2) process requirements and (3) output requirements. Constraints can be seen as a hard limit which the design must meet. Process requirements can be seen as conditions regarding the decision aiding process which have to be fulfilled. Content requirements can be seen as conditions regarding the output of the decision aiding process which must be fulfilled. For the decision aiding approach the requirements are formulated as follows:

I. Constraints

1. **The decision aiding process should involve at least three persons**; at least two decision makers, since otherwise no negotiation can be present, and an analyst.

II. Process Requirements

1. **The decision aiding process should generate a decision making process which is acceptable for all stakeholders involved**; if the process is not acceptable for one or more decision makers, the selected solution will probably also not acceptable for them.
2. **The decision aiding process should have an acceptable duration in time, since it is executed in a business context**; a duration of a process improvement project at ING is on average 4-6 months, which implies a maximum time of about 2-3 months for the decision aiding.
3. **The decision aiding process should allow variety**; variety stimulates learning, which is one of the objectives of the decision aiding process. The decision aiding process design must allow the decision makers to come to variety, especially in the beginning.
4. **The decision aiding process should stimulate trust of the decision makers in the technical evaluation model which is used by the analyst**; without trust in the model, the decision makers will probably have little trust in the validity of the outcomes.

III. Output Requirements

1. **The decision aiding process should result in the selection of a Pareto optimal solution**; selecting a solution which is not optimal would be a waste of potential value.

The requirements are based on the four principles of managing a process of De Bruijn et al. (2010); openness, protecting core-values, progress and substance. The requirements are, however, adjusted to the context of the decision aiding approach. Where De Bruijn et al. (2010) focuses on strategic policy processes, the decision aiding approach is applied in an operational business context. For 'openness' this implies that the process should be open for at least two decision makers. It does not have to be open to everyone, since in the operational context decision power often is more centralised, and thus a decision can be forced by a few important decision makers. For the 'protection of core values' the most important requirement is that the process is acceptable for all stakeholders. This will enhance participation of the different decision makers which is expected to lead to more support for the selected decision. For the principle 'progress' mainly the duration is important. Where in a strategic policy problem the focus tends to be on long term solutions, in a business process this focus tends to be more towards the short term. Due to time constraints and the operational focus of the problem, it is expected that the decision makers aim to select a decision in an efficient manner and strategic behaviour is less present. This results in the requirement that the process of finding a solution cannot have an endless duration and a decision should be selected within maximum three months. The principle 'substance' is reflected in three requirements. First, the process should allow for variety, especially in the beginning since this increases the available knowledge in the process, but in the end the variety must be decreased due to the wish to select a solution. Second, the process should stimulate trust in the results of the model. These quantitative results bring substance to the process, but this is only of value when the decision makers trust the results. Third, the process should end with the selection of a Pareto optimal solution. Related to the principle of progress, the decision aiding process cannot diverge forever with more knowledge and solutions, but in the end a solution must be selected which can be implemented. It is desired that this is a Pareto optimal solution, since selecting a different solution would be a waste of potential value.

3.3 Functions of the Constructive Decision Aiding Process

To reach the objectives as established in Section 3.1, the decision aiding process should perform certain functions. Functions are activities the design must do to successfully reach the objective, but are independent of a certain means. The functions for this decision aiding approach are established based on the function analysis method of Cross (2000). The overall function of the decision aiding approach is to enable the decision makers to select a Pareto optimal solution. This is done based on the semi-structured problem definitions of the involved decision makers. The desired output of the process is a selected solution. So, the decision aiding process transforms semi-structured problem definitions into a selected solution. This is visualised in Figure 3.2.

FIGURE 3.2: Overall function of the decision aiding process

The large overall task 'support the decision makers to select a (Pareto optimal) solution' can be broken down in smaller sub tasks. These smaller tasks refer to actions which need to be done in the final decision aiding process. A representation of the sub tasks is presented in Figure 3.3. The decision aiding process starts with the semi-structured problem definition of the involved decision makers. To create an evaluation model, the problem of the decision maker(s) and his/her preferences should be clear to the analyst (Tsoukiàs, 2008). The problem situation is not entirely clear at the start of a decision aiding process. So, the analyst should aim to establish an overview of the problem situation together with the decision makers. This overview is translated into a formal problem. To come from a problem overview to a formal problem formulation might require some iterations. The decision makers could gather new insight when the formal problem formulation is presented, and therefore change their perception of the problem.

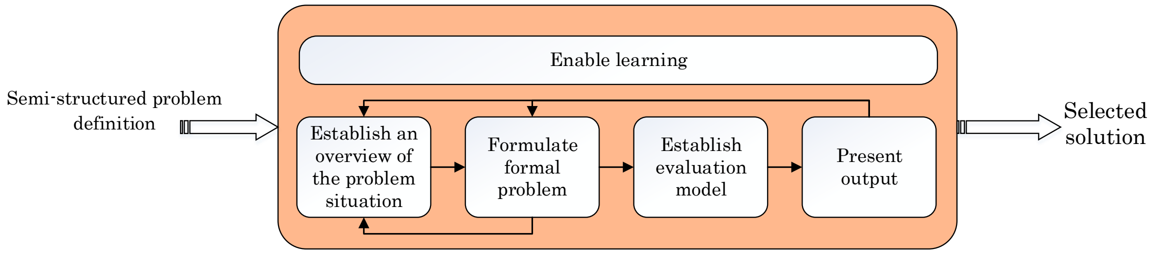


FIGURE 3.3: Sub tasks of the decision aiding process

In addition, through the interactions the analyst learns about the problem which the decision makers experience. Again, a double loop learning cycle can be seen here.

The next task is to create the evaluation mode to provide the decision makers with insight in their problem and possible solutions, from which the decision makers can learn. These insights can be derived from an evaluation model. The evaluation model is established by the analyst and is based on the formal problem (Tsoukiàs, 2008). Based on the output of the evaluation model, the decision makers can reconsider their ideas about the problem due to the new knowledge they gained. Or, it could be decided that the formal problem should be reformulated, which will lead to new output, which in its turn can lead to new possible solutions.

The whole process of establishing a problem overview, developing an evaluation model, and sharing the insight can be seen as a learning process between the analyst and the decision maker(s) (Tsoukiàs, 2008). The analyst learns about the problem of the decision maker(s), and the decision maker(s) learn about their problem and possible solutions, which might change their idea about the problem. This interaction between the analyst and the decision makers, but also between the decision makers themselves, can reshape the analysis and the analysis can reshape the perspectives of the decision makers.

Every sub task has its own input and output. Based on this, several artefacts can be identified which results from the performance of the sub tasks. For the decision aiding approach the following design artefacts are identified:

1. **An overview of the problem situation**; The output of the first sub task is an overview of the problem situation which is shared between the analyst and the decision makers. This overview can be reformulated during the learning process.

2. **A formal problem formulation**; The output of the second sub task is one, or more, problem formulation(s) that are formalised in a way that it can function as the problem definition for the evaluation model. This problem formulation can be reformulated after the learning process.

3. **The evaluation model**; The output of the third sub task is an evaluation model which is used to evaluate the possible solutions upon. In this case, this is a Simulation Optimisation model.

4. **Results of the evaluation model**; The output of the fourth sub task are the results of the evaluation model. In this case the results are the evaluations of the different solutions. These results are presented in a certain visual format which enables the decision makers to understand them.

3.4 Design Variables for the Constructive Decision Aiding Process

Section 3.1 clarified the main goal of the to be designed decision aiding approach, and Section 3.2 and 3.3 set the boundaries for the design by indicating what the design should do which requirements should be met. Together the objective, requirements and functions form the design space, the space in which the design can manoeuvre to reach the objective and fulfil the functions and requirements. The next step is to fill the design space with alternative means to reach the objective, but still cope with the requirements and functions. To do this, the first step is to identify the design variables. These are the variables which can be altered in a certain way to come to different design possibilities. Based on the definition of a decision aiding process and a short search in literature, the following design variables are identified:

1. **Role of the analyst**; which style does the analyst take in the decision aiding?
2. **Sequence**; when comes which step?
3. **Information status**; how formal is the information from the model?
4. **Roles**; who represents which perspective?
5. **Level of decision makers**; what level decision makers need to be involved?
6. **Number of decision makers**; how many decision makers need to be involved?
7. **Duration**; how long does each activity take?
8. **Type of meeting**; individual or collective meetings?

Per design variable the different options will be discussed in the following subsections. Furthermore, the subsections will elucidate on the selection of one of the options for the design. This is done based on which options fits best with the objective of the decision aiding approach and the environment in which it is applied. Not for all design variables a decision can be made. For some design variables the choice depends on the specific case for which the decision aiding is applied. This is the case for the variables 'duration' and 'level of decision makers'. Duration strongly depends on the time pressure which is present in the project, and is therefore decided per case. The level of decision makers strongly depends on the problem, since it is important that the authority of the decision makers matches the problem. Therefore, this is also decided per case.

3.4.1 Role of the Analyst

Franco and Montibeller (2010) identify two different styles which the analyst can use in a decision aiding approach in his paper *Facilitated modelling in operational research*; (1) the expert mode, and (2) the facilitated mode. When using the expert mode the analyst uses methods and models that try to come to an objective analysis of the problem situation and recommend an optimal solution for the problem. The facilitated mode requires the analyst to not only analyse the problem and the possible solutions, but also structure and define the problem together with the decision makers. The two different styles are explained more detailed in Table 3.1. An importation notion which is made concerning the style of the analyst is that subjectivity is unavoidable. Not only is the structuring of the problem subject to the perspectives of the decision makers, also the way the analyst presents the results cannot be completely objective, even if this is pursued. For example, Carlson et al. (2006) showed that the sequence in which information is presented influences the choice people make. So, even though the analyst tries to be as objective as possible, it is necessary to be aware that complete objectivity is hard to reach while facilitating a decision making process.

It is chosen to select the *facilitated style* for the design of the decision aiding process. This style is most appropriate considering the complex, semi-structured problems which are often the topic of a Many-Objective Optimisation and is more focused on learning rather than finding the most optimal solution. This suits best with the objective of the design, as formulated in Section 3.1, and with the decision to use the constructive perspective on decision aiding. When the problem would be a well-structured problem, the export style might be more applicable.

Using this facilitated mode for the decision aiding process implies certain choices in the design. First, the analyst is actively involved in the creation of the problem overview, together with the decision makers. Coming to a shared problem overview might even be one of the most important and time consuming tasks. Furthermore, it implies that the analyst frequently asks for feedback about his/her problem formulation and evaluation model to stimulate that they represent the problem of the decision makers as best as possible, and to ensure awareness of the decision makers about assumptions in the model. In addition, the results will be presented in an interactive way to the decision makers, allowing them to 'play' with the results. The analyst will not present the best solution according to his/her analysis. Instead, the analyst helps the decision makers to explore the results and allow them to make the decision themselves.

3.4.2 Sequence

When one speaks about group decision making, this implies that the decision makers participate in *"designed conversations to exchange their understandings and views about the situation that is being analysed"* (Franco and Montibeller, 2010, p.294). These meetings should take place in a

	Expert mode	Facilitated mode
Framing problems	Problems are a real entity, thus the main task of the operational researcher is to represent the real problem that the client organisation is dealing with, avoiding "biases" from different perspectives.	Problems are socially constructed, thus the operational researcher has to help a management team drawn from the client organisation in negotiating a problem definition that can accommodate their different perspectives.
Formulating problems	The real problem has to be formulated as precisely as possible. It is the task of the operational researcher to formulate the problem.	The problem has to be structured by the management team, whose members are aware about its different aspects and contextual details. The process of problem structuring is supported by the operational researcher, acting as a facilitator, and the development of a model that captures the structure of the problem.
Defining metrics	The expert defines the metrics to assess the performance of options, based mainly on the nature of the problem that the consultant is analysing.	The metrics to assess the performance of options reflect the objectives and priorities of the organisation, as defined by the management team, and with the support of the operational researcher.
Collecting data	Data collection is always extensive and of a quantitative nature. It is the operational researcher that defines, based on the nature of the problem, what information has to be gathered.	Data collection may be extensive, depending on the problem, but involves not only quantitative but also qualitative data and preference information. The objectives and priorities established by the management team guide which information will be gathered.
Evaluating options	The model is solved by the operational researcher, and optimal solutions for the problem are found.	The evaluation of options is conducted interactively with the management team. The consequences of adopting each option are assessed by a model and this informs the team's discussions.
Presenting results	The optimal solutions are then reported back to the client, usually via a detailed report. It is crucial that the report makes explicit all the assumptions made, as the client was not involved in formulating the problem.	Results are shown interactively to the management team. They are allowed "to play" with the model and see the consequences of implementing potential options. The report has typically a less important role, as it is the support for the decision making process that is the key for the client.
Committing for action	The operational researcher hopes that, given the scientific nature of the analysis, the client will be committed to implement its prescriptions.	The operational researcher hopes that the participatory process of reaching a decision, using a facilitated modelling approach, will increase the team's commitment to the implementation of the chosen options.
Paying the consultant	The client pays for the analysis, the prescription of solutions, and the operational research expertise about the problem.	The client pays for the decision support, the recommendations of actions, and the operational researcher's expertise on facilitating the decision making process.
Aim of the intervention	Provide the optimal solutions to the client.	Help the client in learning more about their problem and in gaining confidence for the way forward.

TABLE 3.1: Expert versus facilitated mode (Franco and Montibeller, 2010)

logical sequence for the decision makers (Brown, 2015). This implies that for example meetings concerning the problem structuring should take place before meetings concerning the results of the model, since the output of the problem structuring is necessary to build the model. The tasks which should at least be performed are described in Figure 3.3, and their output also indicates a sequence. Figure 3.3 will therefore be used as the basis for the determination of the sequence of the activities of the decision aiding process. This implies the sequence as visualised in Figure 3.4. It should be said that the number of iterations between the output and the problem depend on the type of decision and organisation. When it is a decision which involves high stakes of the decision makers, they might use more iterations and it is expected that the decision makers can behave strategically and for example block certain decisions (De Bruijn, 2008). When there is a high time pressure, less iterations might be used. In the case of a semi-structured problem, it is expected that several iterations are necessary to come to a proper problem overview, but that the decision makers also aim to solve the problem quickly and are willing to cooperate and make concessions to do this (Keen and Morton, 1978).

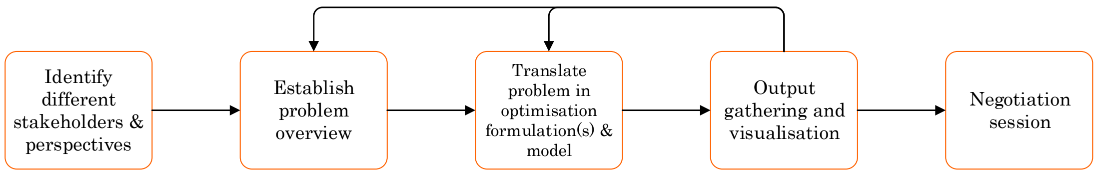


FIGURE 3.4: Proposed sequence

3.4.3 Information Status

The way in which the output of the evaluation model is presented influences the negotiation process. The output can be presented as a soft suggestion what could happen if a certain alternative is implemented, or as the absolute truth. Obviously, this design variable should be seen as a scale and variations in between the two possibilities sketched are possible. Instead of a suggestion, the output can for example also be used as a strong indication what will happen. An important notion to make is that without some substantiated knowledge in the decision aiding process, the decision making can result in endless discussions or unrealistic solutions (Mayer et al., 2005; De Bruijn, 2008). However, due to the complexity of the problems dealt with in a Many-Objective Optimisation, often simplifications and assumptions must be made in the models, which creates the possibility that the output of the model does not correspond with the absolute truth. The choice for the way the information is presented requires a different approach in the decision aiding process. If the decision makers do not have trust in the evaluation model and its output, it will be difficult to present the output as the absolute truth. De Bruijn (2008) states in his book 'Management in networks' that a way to create trust in the information which is presented is to let the different stakeholders negotiate about the knowledge and assumptions which are used to create the evaluation model.

It is decided to select the option *strong indication*. Presenting the output as the absolute truth would not fit the nature of a complex problem. However, having too little substance in the process could lead to a void process without realistic solutions which can be implemented. Using the information as a strong indication for the effect of a solution will provide the process with substance, but still allows for some space for the influence of the assumptions and uncertainties.

An important notion regarding the information is that in an operational process more information will probably be available than in a strategic policy context, since much data is gathered every day about process performance (Keen and Morton, 1978). Since much information is available, it might be easier for the decision makers to agree upon certain assumptions and choices regarding the problem formulation. This makes it easier to set the information status to 'strong indication' than when very little information was available in the process.

3.4.4 Roles

The analyst has the possibility to influence who is on the negotiation table, and should be critical on who is invited and who is not. However, often the analyst is hired by a problem owner, which also wants to have influence on who is involved and who is not. This might limit the possibilities of the analyst to select the involved decision makers. Nevertheless, the analyst could still reflect critically on the choices which are made regarding the involvement of the stakeholders and check for a proper representation of all perspectives. It is important that all identified perspectives of the problem are represented in the decision aiding process, since this increases the variety and increases the chance that the selected solution will implemented (De Bruijn et al., 2010). However, sometimes it is complicated to involve all involved stakeholders in the sessions, for example if it is undesirable to invite a specific type of stakeholder to the sessions. In the example of ING, this is the case for the customer perspective; it is not desired to invite a customer to the session in which the negotiation about the preferred solution takes place, because one customer does not necessarily represent all customers. If it is not possible to involve all stakeholders directly as decision makers, it is important to keep their perspective in mind during the problem formulation and negotiation. This can be done in two ways: (1) divide roles between the present decision makers in a way in which every perspective is represented, or (2) invite a surrogate, someone with proper insights in the stakes of the perspective, to represent that specific perspective.

This design variable can be filled in in two ways. It is preferred to have *all perspectives present* in the negotiation. However, if this is not possible for a good reason, it is chosen to use a *surrogate* for that perspective. This decision is made since a role play in the negotiation changes the dynamics of such a negotiation, since people could be forced to represent an opinion they do not normally share, which decreases the chance that the selected solution will be implemented in the end.

3.4.5 Level of Decision Makers

The decision aiding can take place with different types of decision makers. Different types of decision makers can be operational decision makers, middle-management decision makers, or strategic decision makers (Mintzberg, 1993). Crucial in the decision aiding process is to have the right people on the table. An important criterion for the selection of the decision makers is that they should have enough knowledge about the problem, and enough authority to make and implement the decision. The alignment between the knowledge and authority of the decision makers and the problem formulation is therefore important.

Along with the design variable 'Duration' the selection of the design options regarding the level of the decision makers is done during the decision aiding process. Since it is crucial that the knowledge and authority of the decision makers matches the problem at hand, the level of the involved decision makers can only be determined once there is an idea of the problem situation.

3.4.6 Number of Decision Makers

Besides the level of decision makers, the number of decision makers also influences the decision aiding process. The more decision makers are involved, the more variety the decision aiding process will have due to much different knowledge and ideas. On the other hand, the more decision makers are involved, the more resources (mainly time) are requested from the organisation and it might take more time to agree upon the problem formulation and the selected solution, producing a sluggish decision aiding process. So, a balance should be sought between enough decision makers to create variety, an acceptable amount of resources and sluggishness.

Depending on how many different perspectives are present in the problem, at least one decision maker should be present for each perspective. It can be useful to have not just one decision maker to represent a perspective if there are multiple potential decision makers which have a different expertise, since this will stimulate variety. The more decision makers, the more variety.

It is decided that for the decision aiding process *one or two decision makers per perspectives* will be invited. This number allows for more decision makers when this is valuable for the variety, but limits the number to limit the amount of resources and sluggishness.

3.4.7 Duration

The duration of the whole process depends on the resources of the decision makers and analyst for the project. It is assumed, since this research focuses on projects which are executed in an operational business context, that especially the time of the decision makers is scarce and costly. Therefore, the whole decision aiding approach should not take too much time from the decision makers. However, too little involvement in the process could lead to less confidence in the outcomes of the model (Franco and Montibeller, 2010; De Bruijn, 2008). So, a balance should be sought in the amount of time the decision aiding requires from the decision makers. The duration can also depend on the authority of the involved decision makers. Operational decision makers might need to frequently ask for confirmation from their superiors, leading to a longer duration. Strategic decision makers might miss the detailed knowledge to come to a proper problem formulation, and have to gain knowledge from their staff members, also resulting in a longer duration.

Besides, the intensity of the decision aiding process for both the analyst and the decision makers should be considered. If there is only one month for the whole process available, this will require a lot of time of the decision makers and from the analyst in that one month. When more time is available, for example two or three months, the process will be less intensive for both the decision makers and the analyst. The choice for the intensity depends on the project itself. If there is a strong time pressure to have the results available quickly, this will imply a high intensity.

As stated before, the selection of the design option which fits best for the decision aiding process is made in the decision aiding process itself, since it strongly depends on the problem at hand.

3.4.8 Type of Meeting

During the decision aiding process the decision makers participate in several meetings in which the topic of the decision making is discussed. These meetings can be held with the analyst and an individual decision maker, or with all decision makers together. The decision whether the meetings will be held individually or collectively might influence the dynamics of the meeting. In an individual meeting, the decision maker might speak more freely about his or her ideas, since there is no other stakeholder present which does not agree with the ideas or could interfere. On the other hand, collective meetings might stimulate new ideas since the different decision makers can inspire each other, which will lead to more variety. In addition, in the end a collective decision should be made, and this will be hard without a conversation with all decision makers together. A combination between individual meetings and collective meetings is a possibility as well.

It the decision aiding process, it is decided to have *one meeting with each decision makers individually* for the analyst to learn about their problem perceptions and to gain their trust. After the individual meetings, the problem overview is discussed collectively, so new ideas can arise. The subsequent meeting will all be *collective meetings*, in order to stimulate the decision makers to learn about each others perspectives and stimulate the establishment of a shared problem formulation and evaluation model.

Design variable	Option 1	Option 2	Option 3
Role of the analyst	Expert mode	Facilitated mode	
Sequence	See Figure 3.4		
Information status	Suggestion	Strong indication	The truth
Roles	All perspectives are present	Roles are divided	Surrogate
Level of Decision makers	Operational decision makers	Middle-management decision makers	Strategic decision makers
Number of Decision makers	Maximum 1 DM per perspective	1-2 DMs per perspective	2-3 DMs per perspective
Duration	1 month; high intensity	2 months; medium intensity	3 months; low intensity
Type of meeting	Individual	Collective	Combination

Table 3.2: Design variable options

3.5 Design Choices for the Constructive Decision Aiding Process

Table 3.2 presents an overview of the design variables and their design options. The option which is selected is marked grey. When the selection is done during the decision aiding process itself, none of the options is marked.

Combining all information a decision aiding process is proposed in Figure 3.5. This process is designed for the purpose of a SO being executed in an operational business context to aid a process improvement project. It should be stated that when the decision aiding process is used in a different context, for example where the problem is ill-structured, different choices can be made. A reflection on this changes can be found in Chapter 9.

The process starts off with the analyst being hired by a problem owner to help to solve a problem. It is assumed that there is a certain sense of urgency present to solve the problem, since otherwise the analyst would not be asked for help (Tsoukiàs, 2007). The problem owner often is also involved in the decision aiding process as decision maker, and will probably be a powerful stakeholder in the process. The problem owner will provide the analyst with the first problem description. Based on this, the process starts with the identification of the stakeholders and different perspectives relevant for the problem to be solved (Tsoukiàs, 2007). After the analyst identified the different stakeholders, (s)he must decide who to involve in the decision aiding process. In this step the option for the design variable ‘decision makers’ is selected. The stakeholders who will be involved in the process are all interviewed in individual meetings to get a proper idea about the problem. In this meeting the design variable ‘duration’ of the project is also discussed. When the individual interview leads towards new interesting perspectives to take into account in the decision aiding process, there is the possibility to invite an additional perspective. It is possible to interview stakeholders which are not invited as decision maker to gain more knowledge about the problem. It should be clear, however, why this stakeholder is not invited as decision makers. A reason can be for example that already one or two other decision makers are present which have a similar perspective.

The next step for the analyst is to combine all different problem situations into one structured problem formulation, which (s)he presents to the decision makers for confirmation. At this point iterations can take place, where the analyst adjusts the problem structuring based on the feedback of the decision makers. This can be caused by a misunderstanding between the decision makers and the analyst, or by a change in problem perception of (one of) the decision makers. By allowing such iterations, it is aimed to stimulate trust of the decision makers in the problem structuring.

If all decision makers agree about the problem structuring, the analyst can translate this into a formal model. At this point the methodological knowledge of the analyst is important to come up with a good quality evaluation model (Keen and Morton, 1978; Tsoukiàs, 2007). To create trust in the evaluation model and the outcomes of it, and to stimulate learning, the evaluation model is validated with all decision makers. Again, an iteration can take place here, where the analyst refines the evaluation model based on the feedback of the decision makers.

When the evaluation model is validated, the analyst starts to gather the output of the model. The output will be visualised and presented to the decision makers during a negotiation session. If the output is not satisfactory, for example there is no acceptable solution for all stakeholders, the problem can be reformulated, or the norm which the stakeholders set for the solution can be negotiated. If the output is satisfactory, the decision makers will select a solution during a negotiation session. It is hard to determine on beforehand if the output is satisfactory. This can only be done by the decision makers themselves. When a satisficing solution is selected, the decision aiding process ends. The implementation of the solution is up to the decision makers and is out of scope of the decision aiding process.

3.5.1 In Addition: Hierarchy in the Decision Aiding Process

In contrast to strategic policy problems hierarchy is important for problem solving in an operational context. Where in a strategic policy problem the relationship between the actors can be seen as a network of inter-dependencies, in an operational context some of the relations are unilateral dependencies, such as the relationship between the manager and his/her subordinates (De Bruijn, 2008). This influences the decision aiding process, in essence that some decision makers have more authority than others, and second, that some decision makers implicitly behave according to the hierarchical rules. For example, an employee might not suggest a particular solution since he knows the manager will never be in favour of that idea. The hierarchy is most present at the moments in the decision aiding process where a decision is made.

Even though at any point in the process decision can be made, it is expected that the hierarchy will be of influence at three specific moments: the confirmation of the problem structuring, the validation of the model, and during the negotiation session. For the confirmation of the problem structuring the stakeholders should agree upon the shared problem overview. This process can have multiple iterations, but in the end several decision have to be made to come to this problem overview. It is expected that the decision makers which is highest in rank can influence many of the decisions and determine when the overview is confirmed. For the validation of the model it is expected that if the decision maker with the highest rank does not agree upon the assumptions, the model will not be confirmed by the decision makers. Furthermore, when the decision maker with the most authority does not have confidence in the model, it is unlikely that he/she supports the implementation of the selected solution. During the negotiation session it is expected that other decision makers might anticipate on the preferences of the decision makers with most authority, and that he/she therefore has most power to steer the solution in the direction he/she wants. In addition, this decision maker probably has the power to end the process by forcing a decision. This is in sharp contrast with a strategic policy problem, where all actors depend on each other and it is difficult to force a decision, which can result in a very long negotiation process.

3.6 Chapter Summary

This chapter presented the different design possibilities for the decision aiding process and proposed a design. This decision aiding process will be part of the decision aiding approach which use is demonstrated and evaluated with two cases at ING Bank. The next chapter will elaborate on the design possibilities for the visualisations which will be used to present the output of the evaluation model.

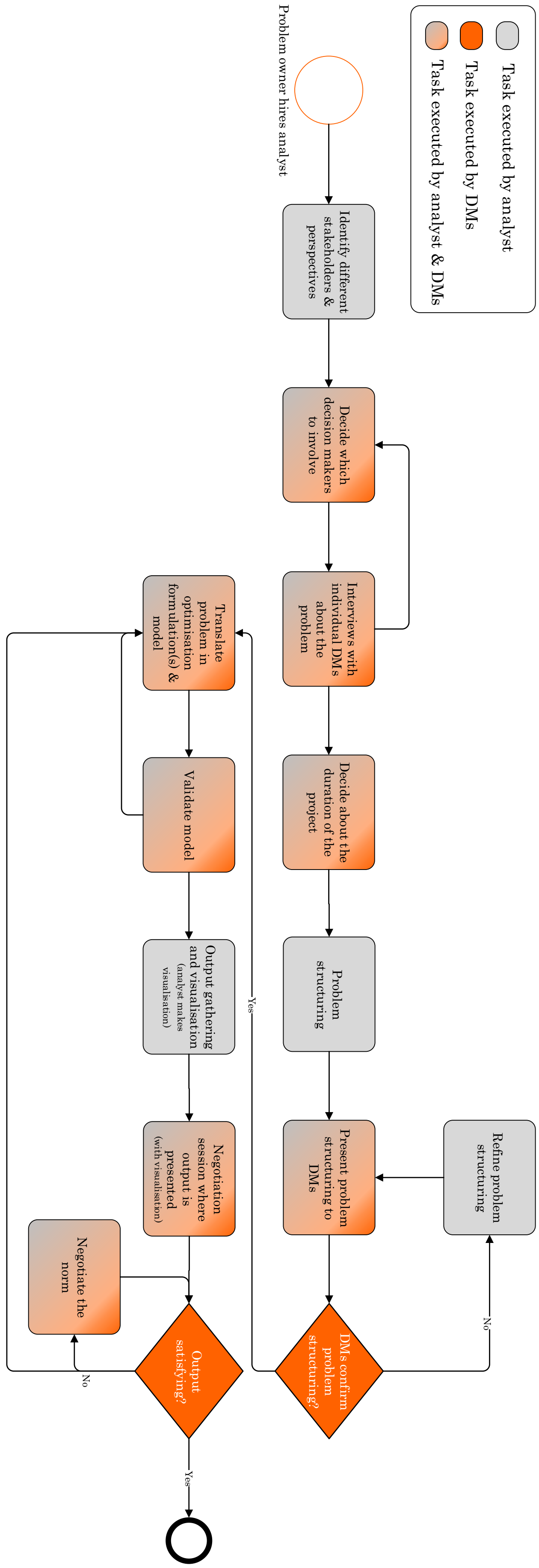


Figure 3.5: Proposed decision aiding process

4 | The Simulation Optimisation Model

This chapter elucidates the design of the simulation optimisation model which is used in the decision aiding approach. This design incorporates two elements: a simulation model and an optimisation algorithm. The first two sections of this chapter follow the design process of Cross (2000) and determine the objective of the optimisation model and the requirements for the model. Section 4.3 discusses the method which is used the create the simulation models for the two cases. Section 4.4 discusses how the simulation model is combined with an optimisation algorithm to become a simulation optimisation model.

4.1 Objective of the Simulation Optimisation Model

The concept 'decision aiding' assumes that a model is used to evaluate possible solutions upon to answer questions of the decision makers. The creation of the evaluation model is not a goal in itself, but the evaluation model is a means to aid the decision makers with their problem. Based on the output of this model the decision makers should be able to make a decision which contributes to solving their problem. Where often in decision aiding research and operational research the evaluation model is mainly used by the analyst to formulate his/her advice to the decision makers, the use of a posteriori Many-Objective Optimisation implies that the decision makers are strongly involved in the interpretation of the results and that the decision makers themselves select the solution which is satisficing (Tsoukiàs, 2007). The objective of the simulation optimisation model in this case is therefore more then finding the optimal solution, since the decision makers themselves determine which solution is best. The objective is *to identify a set of Pareto optimal solutions based on an evaluation of the performance of possible solutions on multiple objectives*. How the results of the model are presented to the decision makers is discussed in Chapter 5.

4.2 Requirements of the Simulation Optimisation Model

Often decision aiding approaches are focused on the construction of this model, and assume there is an existing problem formulation (Tsoukiàs, 2007). However, in the constructive decision aiding approach, it is assumed that the formal problem is not given and that this problem should be established by the analyst and the decision makers together. In addition, the problem overview probably evolves during the decision aiding process, which results in a changing formal problem. Furthermore, the decision makers themselves will be confronted with the results of the evaluation model, not only the analyst. These dynamics imply certain requirements on the evaluation model which is used. The requirements are split in constraints, process requirements and output requirements, following the same structure as used in Chapter 3.

I. Constraints

1. **The simulation model should be combined with an optimisation algorithm**; if the simulation model cannot be combined with an optimisation algorithm, one cannot create a simulation optimisation model.

II. Process Requirements

1. **The model should be easily adjustable to changing problem formulations**; since it is expected that the problem overview evolves over time, the model should be able to cope with this.
2. **The model should allow for the incorporation of multiple stakeholder perspectives**; the objectives and stakes of different decision makers should be incorporated in the model.
3. **The model should allow for the involvement of decision makers in the creation and validation of the model**; since the analyst and the decision makers develop the problem formulation together, the involvement of the decision makers in the model creation and validation can be valuable to come to a better representation of the problem of the decision makers. The model can function as a tool to communicate the formal problem to the decision makers, which allows them to check whether the formal problem correctly represents their needs.
4. **The model should be possible to create within four to eight weeks**; even though the duration of the model creation depends on the number of iterations, the availability of data and the complexity of the problem, it cannot take longer than eight weeks to create the model (excluding the first phase of creating a problem overview), since it is not desired that the decision aiding process takes longer than three months.

III. Output Requirements

1. **The model should result in a set of solutions**; since no prioritisation is given to the objectives a priori, the decision makers should be allowed to determine their preferred trade-off between objectives based on the solution set.
2. **The model resulting solutions should be Pareto optimal**; the resulting solutions have to be Pareto optimal given the used problem formulation.

In addition to the constraints as described, the type of model which is used should be adjusted to the problem at hand. For the case studies, it is decided to use a discrete event simulation model, since this type of model fits to the process improvement problems which are topic of the case studies.

4.3 Creating the Simulation Model

The first part of the simulation optimisation model is the simulation model itself. This model, being a DES model in this research, is the basis for the simulation optimisation model. The creation of this model is approached according to four standard modelling steps: exploration, conceptualisation, specification and validation, see Figure 4.1. In the exploration phase the processes under concern are explored by the analyst to get a general understanding. In the conceptualisation phase the analyst models the processes in a qualitative way. During the specification phase the necessary data is gathered and the model is modelled in a quantitative way. During the validation phase the model is verified and validated. The model is validated by comparing the results of the baseline model with the current real-life situation, and by experimenting with extreme values to see whether the model responds accordingly. After the validation, the results of the model are gathered and visualised. The design of the visualisation is discussed in Chapter 5.

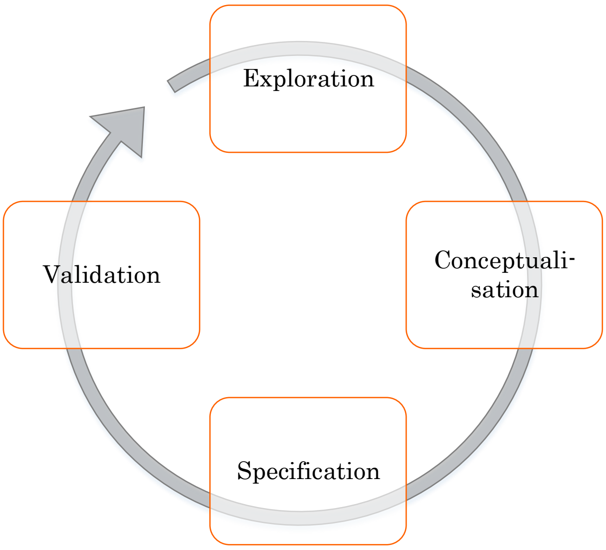


FIGURE 4.1: Four phase modelling cycle

The cycle as described above can be seen as a standard modelling cycle. However, as explained above, the dynamics of a constructive decision aiding approach imply certain requirements on the model. Many of these requirements are concerned with the involvement of decision makers in the modelling process and with the expected iterations in the modelling process. Therefore, it is decided to closely involve the decision makers in each phase of the modelling cycle. During the exploration phase, the involvement is mainly focused on gathering information about which processes are relevant and which aspect of these processes are most important according to the decision makers. During the conceptualisation phase, the analyst regularly checks the conceptualisation with the decision makers. During the specification the decision makers are consulted about the necessary assumptions in the model, the metrics used and which data is gathered and how this is done. The model validation is done together with the decision makers to assure their understanding of the model and to make sure the model represents their problem as best as possible. The validation phase is seen as an important step to increase the confidence of the decision makers in the model.

Even though the phases are structured as a cycle, iterations can take place between the different phases. It is for example possible that during the conceptualisation a part of the exploration phase is repeated or revised, due to a change in the problem scope. Or, once a refinement is identified during the validation phase, a part of the conceptualisation and specification is revised. The modelling approach allows for these iterations.

In the simulation model several solution variables are incorporated. The solution variables can be seen as possible ways to alter the business process, for example the number of employees working on the process. It is expected that a change of the value of a solution variable results in a change of the value of the objectives. The objectives can be seen as performance indicators which are formulated by the decision makers. An example of a performance indicator can be the waiting time of a customer. During the optimisation several combinations of solution variables are evaluated on the objectives. More details on the DES models of the cases at ING Bank can be found in Appendix E and F.

4.4 The Simulation Optimisation Model

The simulation model, of which the creation is described in Section 4.3, should be connected to an optimisation algorithm to create a simulation optimisation model. So far, the model which is created can be seen as a classical simulation model. As explained in Chapter 2 this connection is created manually instead of using a package within the simulation software, since this provides the possibility to use a state-of-the-art algorithm with a good expected performance to optimise many objectives. This manual connection requires certain changes to the simulation model, which would not be necessary otherwise. The connection works as follows. Using an integrated development environment (IDE) for Python programming language a CSV file is generated with random values on the solution variables. These values are extracted by the simulation model from the CSV file. Subsequently, the model runs the defined number of replications with the numerous values of all solution variables. The values of the objectives, being the output of the model calculations, are written to another CSV file. Next, the combination of the values of all solution variables and the resulting performance values of the objectives are pushed to the optimisation algorithm, which uses these values to determine a set of Pareto optimal solutions. A Pareto optimal solution consists of a value for each solution variable and the corresponding performance values on the objective. This whole procedure is coordinated using Python, which enables the process to be fully automated once set up.

The most important changes to the simulation model to facilitate this connection are that (1) the solution variables have to be extracted from a CSV file instead of being defined in the simulation software itself, (2) the performance output on the objectives has to be written to a CSV file instead of using the output statistics from the simulation software itself, and (3) the run setup has to be defined using a 'replicate block' instead of defining this in the normal run setup specification. This last notion is specific to the DES software used in this case study, Arena simulation software of Rockwell Automation. In addition, the output of the optimisation has to be compatible with the visualisation. Therefore, the output is written to a CSV file where each line represents a Pareto optimal solution. This CSV file is transformed to a JSON file which can embedded in the visualisation code.

An important aspect of the simulation optimisation model is the algorithm which is used. Since the decision is made to focus on Many-Objective Optimisation, traditional single objectives algorithms which produce one single optimal solution are not applicable. Instead, a Multi-Objective Evolutionary Algorithm (MOEA) is used. Multiple MOEAs can be found in literature. The choice of algorithm for the optimisation in this research depends on the problem at hand as certain algorithms are better suited for certain types of problems. In this research, it is decided to use the ϵ-NSGA-II algorithm. This decision is made after a quick comparison of several MOEAs based on the criteria 'performance with many objectives', 'computational efficiency', 'run time' and 'availability'. More information about the comparison can be found in Appendix C. The code connecting the simulation model and the optimisation algorithm can be found in Appendix D.

4.5 Chapter Summary

This chapter discussed the objective and the requirements of the simulation optimisation model, which is used in the decision aiding approach to evaluate possible solutions. The creation of the model is approached differently than when only the model is only used by the analyst himself. The decision makers are closely involved during the creation and multiple iterations can take place to adjust the model to a changing problem formulation. In the case study a DES model is created and manually combined with the ϵ-NSGA-II algorithm. Based on the output of the model, a visualisation is created which the decision makers can use to come to a decision. The design of the visualisation is subject of the next chapter, Chapter 5.

5 | Visualising the Output of the Optimisation

The value of visualisation when using Many-Objective Optimisation is explained in Section 1.2.4; visualisations can help the human mind to find meaning in large and complex data sets and in this way overcome the problem of an information overload due to finite human cognitive capacity. The visualisations referred to in this thesis are computer based visualisations of large data sets which are designed to help people to carry out a task more efficient (Munzner, 2014). Designing a visualisation, and especially a visualisation of many-dimensional data, is not straightforward and an unclear visualisation can cause confusion and hence be counterproductive. Therefore, a thorough design of the visualisation, adjusted to the characteristics of MOO and the constructive decision aiding process, is necessary. Again, the design process of Cross (2000) is used to create this design.

5.1 Objective of Using Visualisation

Visualisation is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods (Munzner, 2014, p.1). This implies that the general objective of using visualisations is to *augment human capabilities* by leveraging human visual capabilities to make sense of abstract information (Heer et al., 2005). This is exactly the case when Many-Objective Optimisation with a posteriori decision analysis is used: the computer model does not provide one optimal solution, but the decision makers have to negotiate about the best solution given their different objectives. In the case of Many-Objective Optimisation and a decision aiding approach, the capability which needs to be augmented is the awareness of possible business process improvements. This understanding will support the negotiation about the solutions in the decision making process. In conclusion: the objective of using visualisation in the decision aiding approach is to *augment the awareness about business process improvement possibilities.*

5.2 Requirements for the Visualisation

Since there are endless possibilities for the design of a visualisation, coming up with requirements which steer the design into a direction is valuable (Munzner, 2014). The requirements are divided in two categories: general visualisation requirements, and specific MOO visualisation requirements. The general visualisation requirements are inspired by the principles for graphical excellence of Tufte (1983). The specific MOO visualisation requirements are found in the characteristics of MOO and the goal of the visualisation.

5.2.1 General visualisation requirements

In his book *"The visual display of quantitative information"* Edward Tufte (1983) discusses graphical excellence when it comes to the design of statistical graphs. He defines graphical excellence as *"the well-designed presentation of interesting data - a matter of substance, of statistics, and of design"*. An excellent graph gives the viewer *"the greatest number of ideas in the shortest time with the least ink in the smallest space"* Tufte (1983, p.51). The requirements are split in constraints, process requirements and output requirements, following the same structure as used in Chapter 3.

I. <u>Constraints</u>

1. **The graph should be integer**; the graph must tell the truth about the data. The representation of the data measured on the surface of the graph, has to be directly proportional to the numerical quantities represented. Furthermore, clear, detailed, and thorough labelling should be used to defeat graphical distortion and ambiguity.

II. <u>Process Requirements</u>

1. **The graph should provide the user with both an overview and a detailed view**; both views are necessary to communicate the full content of the data.

III. <u>Output Requirements</u>

1. **High data-ink ratio**; the data-ink ratio is the ink used to print data divided by the total amount of ink used to print the graphic. Every bit of ink must have a reason, and almost always that reason has to be that the ink contains new information.
2. **No chartjunk**; chartjunk is the interior decoration of graphics. Often this is ink which does not provide new information to the user.
3. **High data density**; the data density is the numbers of entries in the data matrix divided by the area of the graph. Too little data in a graph decreases the credibility. Furthermore, a dense graph makes the eye more comparative and effective.
4. **Balanced relative proportions**; graphical elements have a nicer appearance when their relative proportions are in balance. For example: a consistent scale looks more clear and more appealing than an inconsistent one.
5. **Shape toward the horizon**; horizontally stretched figures are more accessible to the eye. Design a graph greater in length than in height, unless the nature of data suggests otherwise.

6. **An accessible complexity of detail**; graphs should not be graphic puzzles. Data can be supported with words to give access to the richness of data. This should, however, be designed in a 'friendly' way, see Table 5.1.

Friendly	**Unfriendly**
Words are spelled out, mysterious and elaborate encoding avoided	Abbreviations abound, requiring the viewer to sort through text to decode abbreviations
Word run from left to right, the usual direction for reading occidental languages	Words run vertically, particularly along the Y-axis; words run in several different directions
Little message help explain data	Graphic is cryptic, requires repeated references to scattered text
Elaborately encoded shadings, cross-hatching, and colours are avoided; instead, labels are placed on the graphic itself; no legend is required	Obscure coding requires going back and forth between legends and graphic
Graphic attracts viewer, provokes curiosity	Graphic is repellent, filled with chartjunk
Colours, if used, are chosen so that the colour-deficient and colour blind can make sense of the graphic	Design insensitive to colour-deficient viewers
Type is clear, precise, modest	Type is clotted, overbearing
Type is upper-and-lower case, with serifs	Type is all capitals, sans serif

Table 5.1: Difference between friendly and unfriendly graphics (Tufte, 1983, p.183)

5.2.2 Specific MOO Visualisation Requirements

The designed visualisations must be suited for the method of Many-Objective Optimisation, and the environment in which they are used, an operational business context. This results in the following requirements, which are again divided into constraints, process requirements and output requirements.

I. Constraints

1. **The graph should allow for many dimensions**; since the purpose of a MOO is to optimise multiple objectives all at once, the output data will be many dimensional. The graph should be able to present those dimensions.

II. Process Requirements

1. **The graph should allow the users to play with data**; the objective to understand trade-offs between different objectives and solutions asks for the possibility for the users to experiment with values of the objectives for different solutions.
2. **The graph should not take a long time to understand**; since the graph is used in a business context where time is scarce, the graph should not take a long time to explain and understand. It is aimed that the decision makers understand the working

of the graph within 15 minutes. The understanding of the content of the graph is not included in this time frame.

III. Output Requirements

1. **The graph should allow for the selection of one solution**; in the end the decision makers should be able to select one solution. The graph should support this selection.

5.3 Functions of the Visualisation

The same data set can be visualised in different ways. A crucial consideration for how the data can be visualised effectively is the task for which the visualisation is used (Munzner, 2014). In the case of MOO, the objective of the visualisation is to *augment the awareness about the effect of solutions and about trade-offs between objectives*. To be able to do this, several functions are necessary. These functions are identified by breaking down this objective in small demarcated sub tasks. An overview of the functions is presented in Figure 5.1.

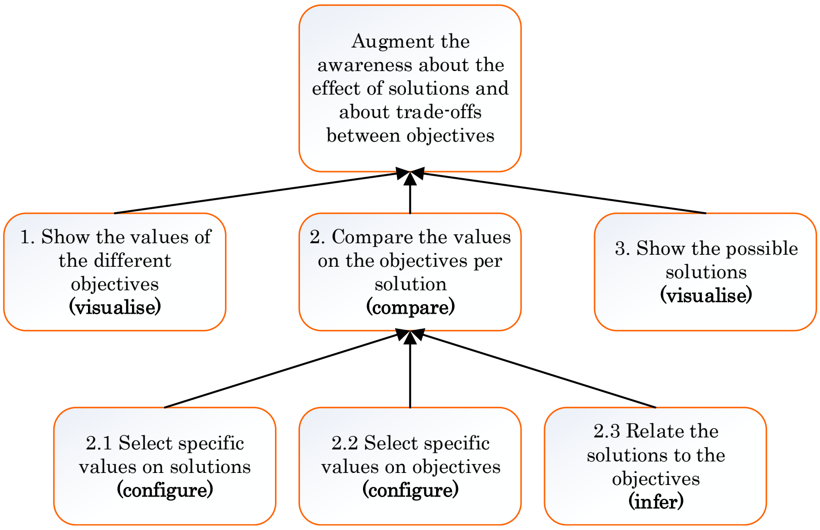


FIGURE 5.1: Functions of a visualisation used to support MOO

Function 1 and 3 of the graph are quite straightforward; the graph has to show the possible solutions and the values on the objectives. Function 2 connects the solutions to the objectives, by making it possible to compare the values on the objectives depending on the solution, and vice versa. This functions entails the sub function to filter specific values on the solution variables, the sub function to filter specific values on the objectives, and the sub function to relate the solutions to the objectives, and vice versa. This last sub function allows for a comparison of the performance of different solutions on the objectives, and allows for the exploration of trade-offs between different objectives.

The functions as just explained can be seen as domain specific functions, being functions which are specific for the use of MOO. These functions can be related to more general functions of visualisation. In literature, several taxonomies can be found which make it possible to relate domain-specific tasks to general functions often used in visualisation, such as Springmeyer et al. (1992); Valiati et al. (2006); Wehrend and Lewis (1990); Zhou and Feiner (1998). In this thesis the taxonomy of Valiati et al. (2006) is used. This taxonomy is found to be valuable since it integrates analytic functions, cognitive functions and operational functions at different levels and is proposed especially to support the design of multidimensional visualisation techniques. The taxonomy comprehends seven functions: identify, determine, visualise, compare, infer, configure and locate, which are each explained in detail in their paper *"A Taxonomy of Tasks for Guiding the Evaluation of Multidimensional Visualizations"* (Valiati et al., 2006). The domain related functions are matched to one of the functions of the taxonomy to create a clear overview of what to design should encompass, and can also be found in Figure 5.1.

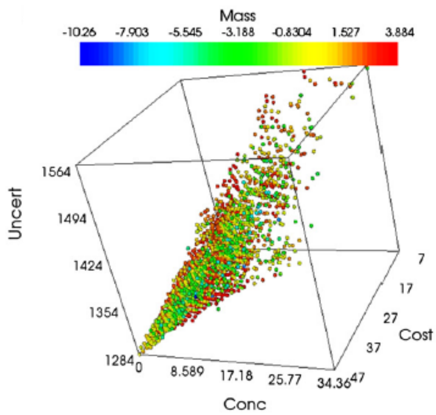
The functions indicate what the design should do to support the decision makers during the decision aiding approach. Based on the functions, the design of the visualisations will be conducted.

5.4 Design Variables for the Visualisation

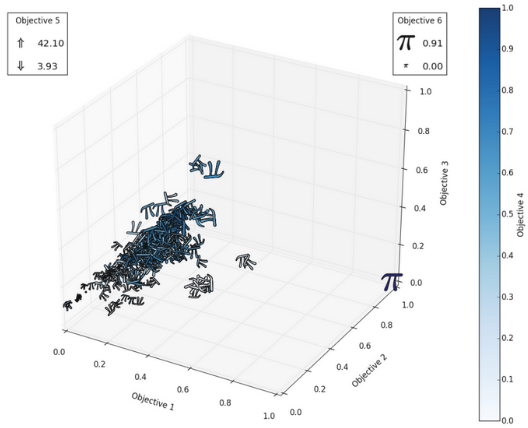
Munzner (2014) states that analysing existing visualisation designs is a good start for designing new ones. It is decided to analyse common used graphs and techniques to visualise MOO output, to come up with the design variables. The design variables can be divided in two categories, according to Munzner (2014): visual encoding (what users see, static) and interaction (how users change what they see, dynamic). It is seen that two types of visualisations dominate in use in literature and application of MOO: the 'parallel coordinate plot' and the 'Pareto front plot'. Both types can have several variations in for example the number of dimensions, colours and shape. Several examples are presented below in Figures 5.2a - 5.3c. Each figure is analysed to come up with design variables. Examples which contain less than three objectives are excluded.

The graph in Figure 5.2a is an example of a Pareto front plot and uses a 3D view of a Pareto front to show the scores on four different dimensions. The first three dimensions correspond with the axes of the plot, the fourth corresponds with a colour scale. The data points are plotted as round dots. The visualisation uses axes with a scale and a label and no grid is present. The image is rotated so the viewer sees the graph from a certain view.

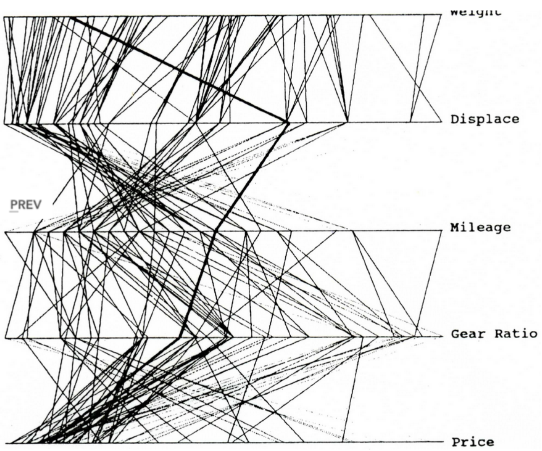
The graph in Figure 5.2b uses also a 3D view of a Pareto front, but show the scores on six different dimensions. The first three dimensions correspond with the axes of the plot, the fourth corresponds with a colour scale, the fifth with the direction of the shape (facing upwards or downwards) and the sixth objective is represented by the size of the shape. The objectives are



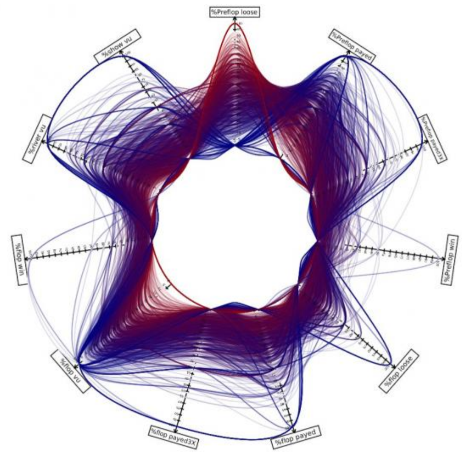
(A) Pareto frond plot from Kollat and Reed (2007a)



(B) Pareto front plot from Zatarain (2016)



(C) Parallel coordinate plot from Wegman (1990)



(D) Parallel coordinate plot from Tulip (2009)

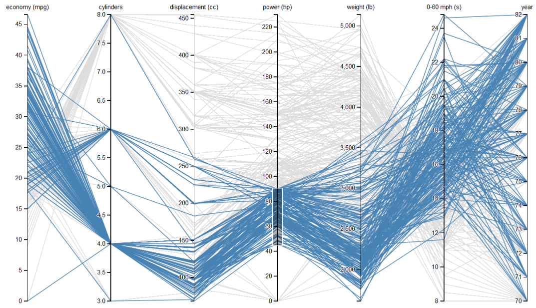
FIGURE 5.2: Visualisation examples (1/2)

explained in a legend. The visualisation uses axes with a scale and a label and a grey grid is present.

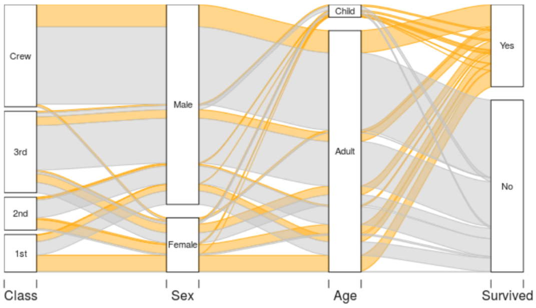
The graph in Figure 5.2c is a parallel coordinate plot which shows the scores on five objectives. Each objective has his own axis and is labelled with the name of the objective. All lines have the same colour, black.

The graph in Figure 5.2d is a parallel coordinate plot as well, but instead of horizontally or vertically oriented, this graph is shaped as a circle. The lines are curved instead of straight and different colours are used to indicate an order in objective scores. The objectives are presented with scaled and labelled axes.

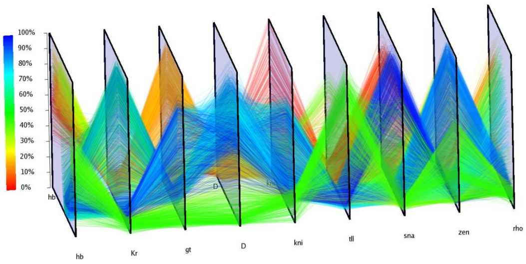
The graph in Figure 5.3a is a parallel coordinate plot which shows the scores on seven objectives.



(A) Parallel coordinate plot from Davies (2017)



(B) Alluvial plot from Trindade (2017)



(C) 3D parallel coordinate plot from Sager (2009)

FIGURE 5.3: Visualisation examples (2/2)

Each objective has his own scaled axis and is labelled with the name of the objective. The graph is interactive; it is possible to select a range on an axis of an objective. The selected lines, which all represent a solution, are given a different colour than the solutions which are not selected. Furthermore, it is possible to change the sequence of the objectives.

The graph in Figure 5.3b is an alluvial plot, which can be seen as a plot related to a parallel coordinate plot. In this example, it is used to group different data points in categories. The axes are divided in parts which represent how many data points belong to that category. The thickness of the line, called alluvium, indicates how many data points fall within the same categories across all axes. Such a plot can also be created when the objectives are continuous, and when there is a special interest in a data point meeting a certain performance criteria instead of the actual objective values. Colours are used to separate data points which meet a certain criterion from the others.

The graph in Figure 5.3c is again a parallel coordinate plot, but in a 3D view. The axes are labelled with the names of the objectives, but there is no scale present. A colour scale is used to provide additional information.

In practise and in literature many more examples of visualisations can be found. The figures in Figure 5.2 and 5.3 are found to provide us with a diverse overview of the most common used visualisations. Analysing the graphs leads towards the design variables in Table 5.2. However, especially on interactions the examples are quite limited. Only Figure 5.2a and Figure 5.3a use interaction to allow the user to change the graph. Table 5.2 therefore only shows the design variable for visual encoding.

Visual encoding				
Design variable	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Graph dimensions	2D view	3D view		
Shape	Horizontal oriented	Vertical oriented	Circle	
Axes scale	With scale	Without scale		
Axes label	With label	Without label		
Axes division	Categories	Continuous	Logarithmic	
Legend	With legend	Without legend		
Background	Transparent	Grid	Coloured filling	
Use of colour	Only one colour	Colour to group	Colour to separate	
Colour	Hue	Saturation	Luminance	Transparency
Data point shape	Circle	Line	Other	
Line shape	Straight	Rounded	Thick	Thin
Data points	Single points	Grouped points		

TABLE 5.2: Design variable options for visual encoding

The book *'Visualisation Analysis & Design* of Munzner (2014) presents an overview of design possibilities to manipulate the view. Especially in large and complex data sets, such as Many-Objective Optimisation output, interactivity is important to grasp the information. Limitations of both humans and information displays prevent showing everything at once in detail (Munzner, 2014). Where it is important to show the user an overview of all data, this can lead to overwhelming visual clutter, as for example can be seen in Figure 5.2b and Figure 5.3a. Interactive tools allow for changing views, scope and level of detail, which makes it easier to connect the information.

Munzner (2014) identifies many possible design choices to allow interaction. Only the options which are considered relevant for the visualisation of MOO output are shown in Table 5.3. This selection is done based on the function requirements, as described in Section 5.3. The next paragraph briefly explains the different interaction design variables and their options. A detailed description of all design variables and the options can be found in Munzner (2014).

The design variables 'data point reduction' and 'objective reduction' can be seen as a possibility to reduce the complexity of a graph. Reducing the number of data points implies for example showing less lines in a parallel coordinate plot. Reducing the number of objectives reduces the number of dimensions in the graph. When in one of the reduction variables the option 'select' is chosen, there are different possibilities to implement this. First, it should be decided which 'element' is selected; is it for example possible to select a data point itself, or an objective?

Second, the 'selection technique' should be chosen; what action does the user use to execute the selection? Highlighting is a design variable which is related to selection. The graph has to respond in a visual manner to the selection of the user. This can be done by 'highlighting' the selected value(s) for example by a change in their colour or shape. The design variable 'viewpoint' can be changed to better explore the full graph. Especially in 3D graphs, this can be useful. The option 'rotate' is, for example, used in Figure 5.2a, to be able to see all data points properly. The design variable 'change sequence' changes the appearance of the graph, which might make it easier to relates the different objectives. In Figure 5.3a it is for example possible to change the sequence of the objectives.

Interaction				
Design variable	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Data point reduction	Select	Filter	Aggregate	None
Objective reduction	Filter	Aggregate	None	
Selection element	Select data point	Select on attribute value	Select one element	Select multiple elements
Selection technique	By mouse click	By mouse hover		
Element highlighting	Change colour	Change size	Change outline	Change shape
Change viewpoint	Geometric zooming	Semantic zooming	Rotate (3D)	Navigate (2D)
Change sequence	Change sequence of objectives	Invert scale of axes		

Table 5.3: Design variable options for interaction

5.5 Design Choices for the Visualisation

The solution space for static visual encoding is large, and the interaction possibilities make it even larger. Choices for the design variable options should be based on the match between the task the user has to perform and the design possibilities, and the general guidelines for visualisations. According to Munzner (2014) this assessment should be done based on the understanding of human abilities, especially in terms of visual perception and memory. Table 5.4 shows an overview of the choices made for the final design, and Figure 5.4 shows the final design. The motivation regarding the design choices made is explained in Section 5.5.1 and 5.5.2. In these subsections supplementing graphs are presented which show the step by step creation of the graph.

5.5.1 Design Choices on Visual Encoding

The design variable 'graph dimensions' is chosen as a starting point for the design of the visualisation. This is seen as a logical point since many of the subsequent choices on the other design variables depend on the number of dimensions of the graph. It is decided to select a *2D view*, since it is seen that people often have difficulties to grasp the information which is stored in the

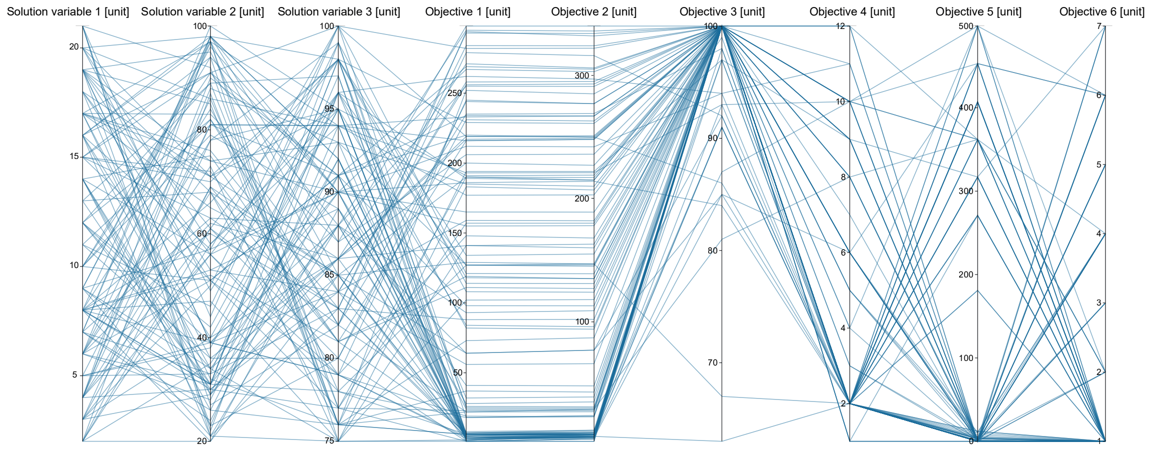
Visual encoding				
Design variable	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Graph dimensions	2D view	3D view		
Shape	Horizontal oriented	Vertical oriented	Circle	
Axes scale	With scale	Without scale		
Axes label	With label	Without label		
Axes division	Categories	Continuous	Logarithmic	
Legend	With legend	Without legend		
Background	Transparent	Grid	Coloured filling	
Use of colour	Only one colour	Colour to group	Colour to separate	
Colour	Hue	Saturation	Luminance	Transparency
Data point shape	Circle	Line	Other	
Line shape	Straight	Curved	Thick	Thin
Data points	Single points	Grouped points		
Interaction				
Design variable	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Data point reduction	Select	Filter	Aggregate	None
Objective reduction	Filter	Aggregate	None	
Selection element	Select data point	Select on attribute value	Select one element	Select multiple elements
Selection technique	By mouse click	By mouse hover		
Element highlighting	Change colour	Change size	Change outline	Change shape
Change viewpoint	Geometric/ Semantic zooming	Rotate (3D)	Navigate (2D)	None
Change sequence	Change sequence of objectives	Invert scale of axes		

Table 5.4: Design choices for the visualisation

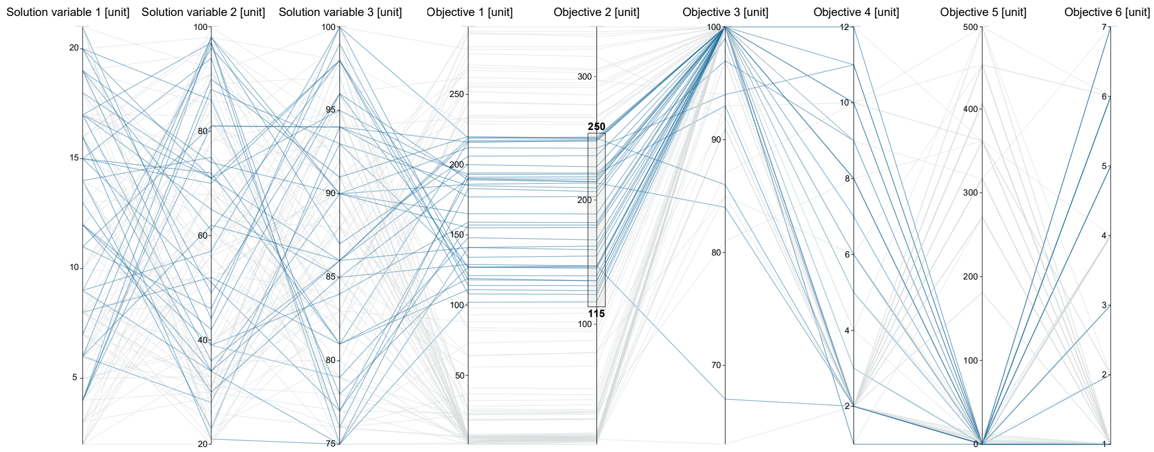
third dimension; depth. St John et al. (2001) states that 3D displays hamper the judgement of relative positions. Using a 3D graph can however be useful when the user's task involves shape understanding. Since the goal of the visualisation to be designed in this research does not involve shape understanding, and the judgement of relative positions is important to increase the awareness of the effect of solutions, a 2D view is selected.

The decision to select a 2D view implies the 'Pareto front plot' is not used as format for the visualisation. So, all objectives, which correspond to a dimension in the data set, should be plotted in a 2D graph, as is the case for a parallel coordinate plot. It is decided to take this type of graph as a starting point for the design.

As for the design variable 'shape' it is decided to select the option *horizontal*. This choice is derived from the requirements as explained in Section 5.2, which state that a horizontally shaped graph is more accessible to the human eye. It is therefore decided to use vertical axes, as can be seen for example in Figure 5.3a, which are placed horizontally side by side. Both



(A) Designed visualisation overview with dummy data



(B) Designed visualisation with selection (dummy data)

FIGURE 5.4: Designed visualisation with dummy data

the objectives and solutions are placed next to each other in the same graph. In accordance with the requirement 'graph integrity' it is decided to uses axes *with scale* and *with labels*. This avoids confusion and ambiguity, and makes it easier for the decision makers to create a shared understanding. How the axes are divided depends strongly on the type of data which is used. If the data is continuous, the division should be continuous. If the data is categorical, using a continuous axis makes little sense. So, this design variable should be decided based on the data set which is used in the visualisation. An example of a graph with labels on the axis can be seen in Figure 5.5.

Following the guidelines for 'friendly graphics' of Tufte (1983) it is decided to *not use a legend*. Since the axis are labelled and a scale is used, it is expected that the data itself is clear, and adding a legend would make the graph unnecessary complex. To maximise the data-ink ratio,

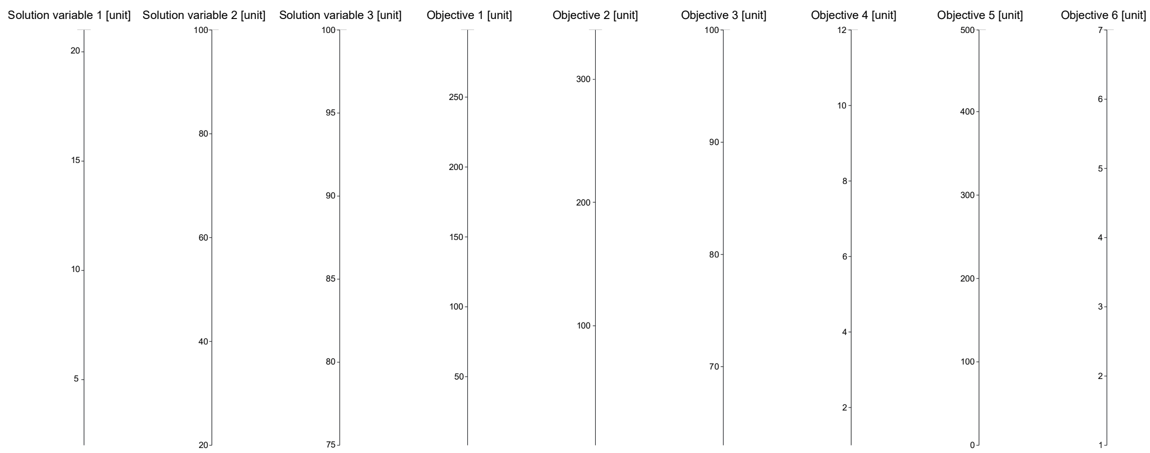
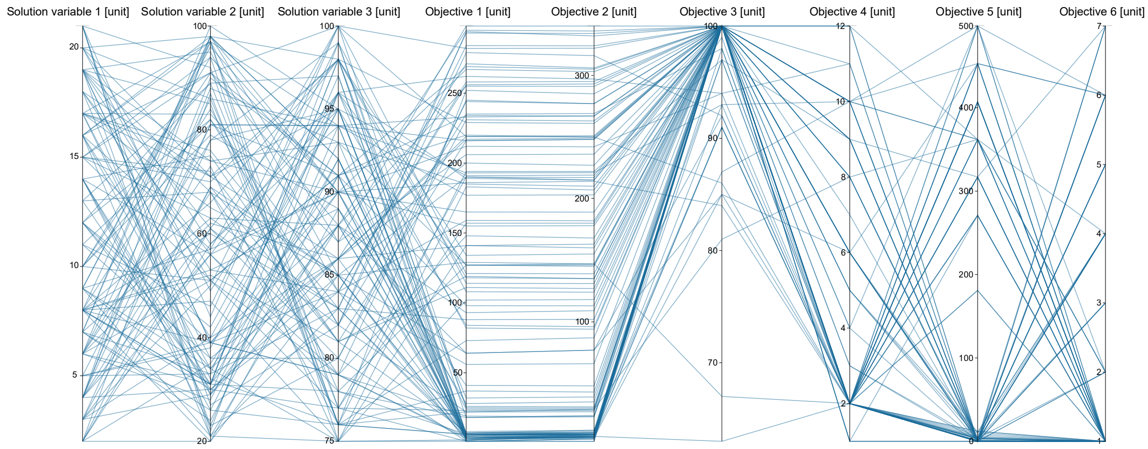


FIGURE 5.5: Graph with vertical axes representing solution variables and objectives

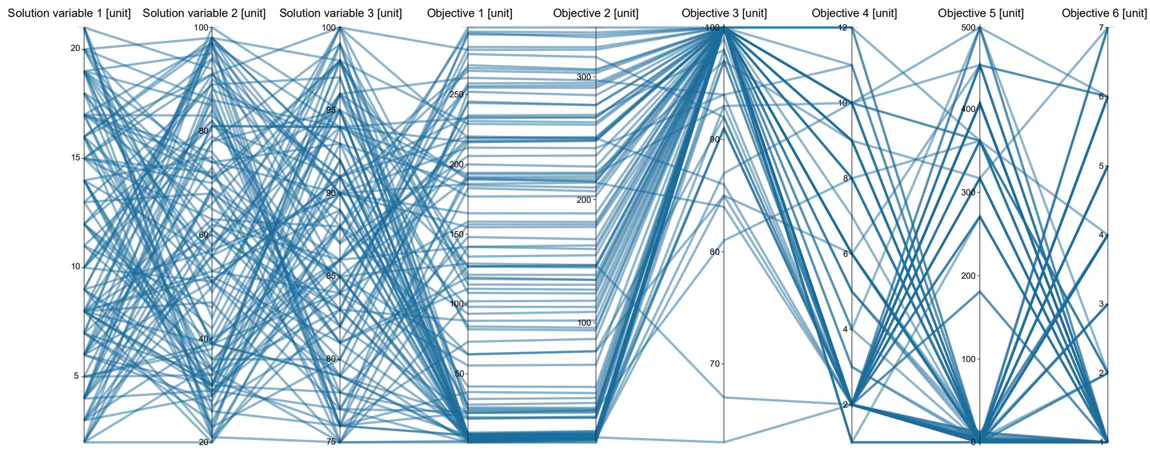
it is decided to use a *transparent* background which will be seen as a white background.

For the design variable the 'use of colour' decisions should be made carefully; colour can be an important source of confusion, since it is sometimes carries the identity of a data point and sometimes carrier the magnitude of a data point. An example when colour is used as identification manner is when pink dots represent women and blue dots represent man. An example where colour is used to indicate the magnitude is a heat map, where the colour indicates the height of the temperature. To keep the graph plain it is decided not to use many different colours. For the labels and scale of the axes the colour black is used; this is in sharp contrast with the white background which makes the labels and scales clearly visible. For the axes itself, the colour grey is used. The labels and scale values are more important, and the axes can be seen as some kind of grid which is useful, but does not need to be in the foreground of the graph. For the data points it is desired to use a different colour than for the other graphical elements, since it is important that the data points stand out. Blue is used as colour for the data points. Blue proved to be the colour which most people can differentiate clearly, also individuals with colour blindness. *Luminance* is used for the blue colour to indicate the density of the data points.

With the selection of a parallel coordinate plot, the logical choice is to use *lines* as the shape for the data points, since only lines can make the connection between the different objectives on the different axes. It is decided to use *straight* and *thin*. It is seen that using thick lines makes the plot even more a clutter that when thin lines are used. The data points are plotted as *single points* since in the end the task of the decision makers is to select one solution. Figure 5.6 shows the difference between thick and thin lines. Figure 5.6a is selected as basis for the further design.



(A) Graph with thin lines



(B) Graph with thick lines

FIGURE 5.6: Difference between thin and thick lines

5.5.2 Design Choices on Interaction

Once the static view of the graph is designed, it is time to add the interaction components to the graph. The interaction components will allow the user to make sense out of the clutter of lines it may seem at first sight. The design of the interaction components is based on the functions of the visualisation, as established in Section 5.3. The main functions where interaction components play a role is in the task 'compare the values on the objectives per solution'.

The interaction design starts selecting the design variables which deal with reduction. Reduction is seen as an important way to reduce the complexity of a graph (Munzner, 2014). For the design variable 'data point reduction' the option *select* is chosen. The reason why the option 'select' is chosen over 'filter' is for the reason to avoid the risk on "out of sight, out of mind". When the user filters the data points for example on a specific attribute value, all data points which does not fulfil that constraint would be 'out of sight'. This leads to the risk that those data points are forgotten, while there might be a data point very close to the desired attribute value which might score better than other data points on other objectives of the user. By using the 'select' option, all solutions stay "in sight", but the selected data points get highlighted.

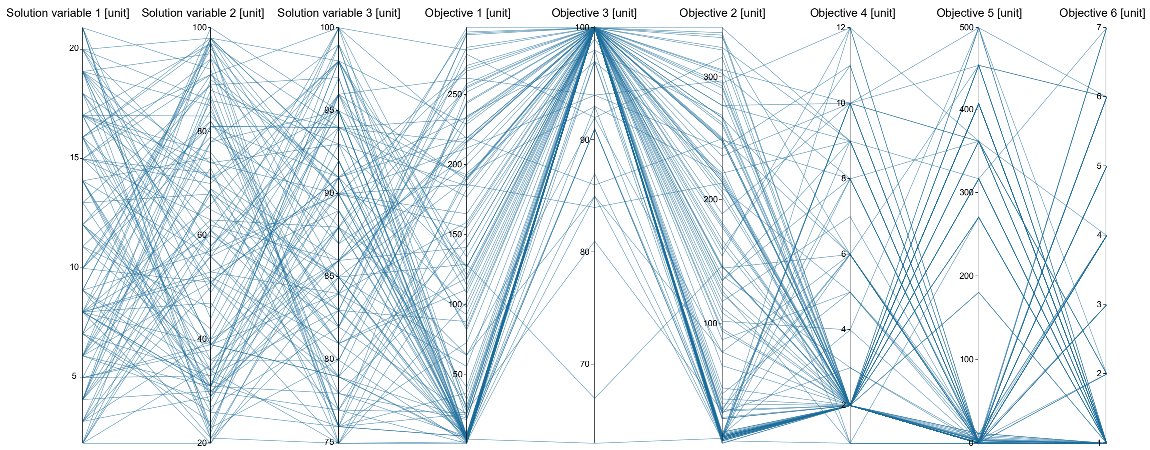
The way to reduce the number of objective depends on the data set under concern. Filtering is again seen as undesirable due to the risk at "out of sight, out of mind", and by filtering on specific objective the trade-offs amongst them are less visible. Aggregating objectives could be useful when there are multiple objectives which are strongly correlated, which might make them redundant. If this is not the case, aggregating objectives might lead to a decrease in visibility of the trade-offs, which is not desired. Thus, the option on this design variable should be selected based on the data.

Since the design variable 'data point reduction' involves selecting data points, the design variables 'selection element', 'selecting technique' and 'element highlighting' become relevant. It is decided to allow for selection *on attribute value.* This is chosen since the value on the objectives are expected to be the most important constraints for selecting a solution. Furthermore, it is decided to allow for the selection of *'multiple elements'*, so the values of multiple attributes can be selected. By selecting the desired (range of) attribute value(s), the data points which are located in that range get highlighted. The selection is done by starting with *mouse click* at the one end of the selection range and dragging the mouse to the other hand of the selection range. The range which the user selects in labelled; the minimum and maximum of the selection are shown. This avoids ambiguity which range exactly is selected.

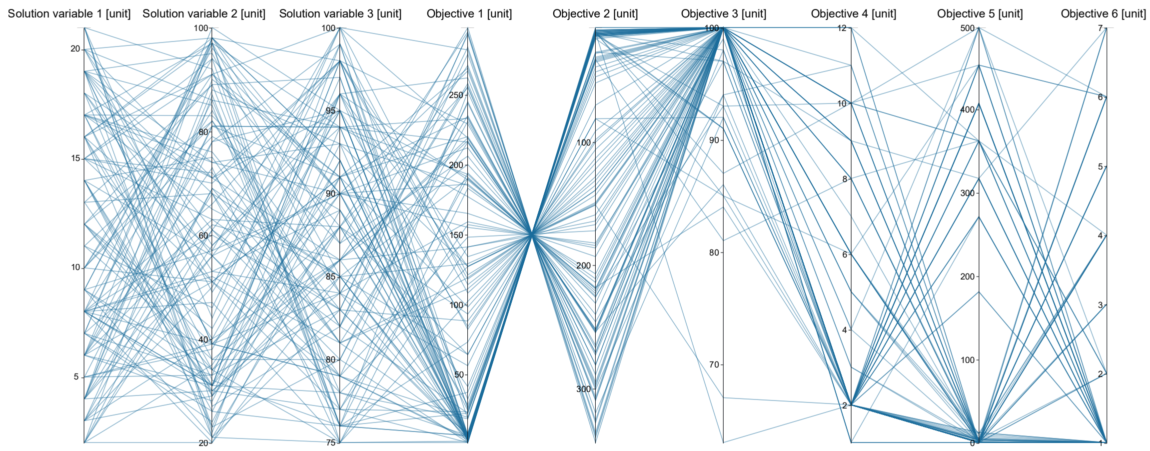
The design variable 'highlighting' is important in combination with the selection function. Highlighting changes the appearance of the selected elements, which is an immediate visual feedback to the user. The highlighting can work two ways; elements which are selected can change, elements which are not selected can change, or both. It is desired to *change the colour* of the data points which are not selected to almost transparent blue. For the data points which are selected the *size* is changed; the stroke width of the line is increased.

Considering the design variable 'change viewpoint' none of the design options is considered relevant. It is believed that for a proper use of the parallel coordinate plot navigating through the plot is undesired, since this hampers a proper exploration of the trade-offs between the objectives. When not all objectives can be seen at once, the effect of selecting a specific solution cannot be seen for all objectives, resulting in more difficult comparison of solutions and objectives
.

The last design variable who allows the user to change the view is the variable to change the sequence of the elements in the graph. Both options *change sequence of objectives* and invert



(A) Graph with a changed sequence of the axes



(B) Graph with one axis being inverted

Figure 5.7: Interaction possibilities

scale of axes can be valuable to find patterns in the data set and in this way enable the user to better explore trade-offs between objectives and the effect of possible solutions. To change the order of the objectives, the user can drag the objective to the desired position. To invert the scale of the axis, the user can double click on the label of the specific axis. An example of the graph with a changed sequence or an inverted scale can be found in Figure 5.7.

5.6 Chapter Summary

Based on general visualisation requirements and specific MOO visualisation requirements a graph is designed which is used during the decision aiding approach. This graph is meant to *augment the awareness about trade-offs between different objectives and solutions*. Chapter 7 demonstrates how this visualisation design as a part of the decision aiding approach is applied on the two case studies. Chapter 8 elaborates on the evaluation of the visualisation design.

6 The Three Design Artefacts as One Integrated Design

Chapter 3, 4 and 5 elaborated on the three design artefacts which together form the decision aiding approach. To come to a coherent decision aiding approach which can be applied to the two cases, the three elements are integrated. This chapter explains how this integration is done.

6.1 An Overview of the Three Artefacts

Figure 6.1 shows the three design artefacts. The first design artefact is the constructive decision aiding process. This process can be seen as a stepwise guidance for the analyst executing the decision aiding approach. The process starts off with creating an overview of the problem, identifying stakeholders and formulating a problem overview together with all involved stakeholders. Next, the SO model is designed and validated. The results of this model are discussed during a negotiation session, which is the final step of this process. The process allows for many iterations for the problem formulation and model creation, since this is needed to be able to deal with the evolving problem formulations during the process. An overview of the decision aiding process can be found in Figure 3.5.

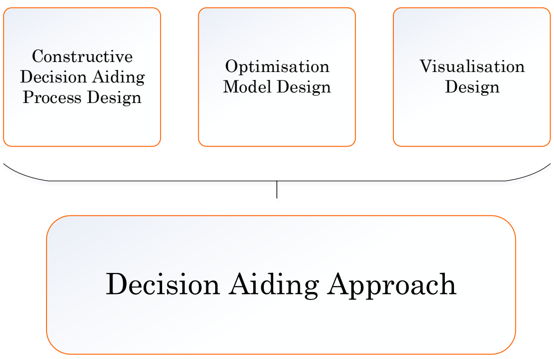


Figure 6.1: Three different designs within the decision aiding approach

The second design artefact is the simulation optimisation model. What type of simulation model is used, depends on the problem at hand. For the two case studies, a Discrete Event Model is designed which is combined with the ϵ-NSGA-II algorithm to do the optimisation. Even though this thesis uses a DES model as simulation model, the decision aiding approach can also be suitable for other types of models, such as system dynamics, as long as they can be connected with a MOEA, and the creation process allows for multiple iterations and the involvement of the decision makers. A description of the SO models used in the two cases can be found in Appendix E and F.

The third design artefact is the graph which is used to visualise the results of the SO model. This visualisation is crucial to give meaning to the results from the SO model and to deal with the risk of an information overload. The designed visualisation is a type of parallel coordinate plot which is horizontally oriented. The most left axes represent the different solution variables, the other axes represent the objectives. The user can interact with the graph and manipulate the view by selecting specific ranges on interest on the different axes. An overview of the designed visualisation is presented in Figure 5.4. It is believed that the parallel coordinate plot is the most suitable type visualisation for exploring the effect of solutions on objectives and for exploring dependencies between objectives when there are more than three dimensions in the data set.

The decision aiding process can be seen as the process which can be followed step by step. The other two artefacts are created and used during this process. Creating the SO model is part of the process, and is done during the step 'translate problem in optimisation formulation(s) and model'. The validation of the model is done during the step 'validate model'. As explained in Chapter 4 the decision makers are involved during this steps to stimulate improvements of the problem formulation. The output of this model is visualised using the designed graph. This graph is created in the step 'output gathering and visualisation' and is presented to the decision makers in the step 'negotiation session where output is presented'. During this session, the decision makers can interactively play with the graph to gather new knowledge to make a decision. The decision aiding approach commences with creating a problem overview and concludes with a decision of the decision makers, and guides the analyst through the project of aiding a group of decision makers to select a business process improvement solution. An overview of the three artefacts forming the decision aiding approach can be found in Figure 6.2.

6.2 Integration of the Three Artefacts

How do the three artefacts come together in the decision aiding approach? Do they follow each other sequentially? How do they depend on each other? Would the approach still work when one of the artefacts is not present? The three artefacts come together in the decision aiding approach, where the decision aiding process can be seen as the step by step guide in which the SO model and the visualisation are created and used. The three artefacts do not necessarily follow each other sequentially. The approach starts off with the decision aiding process, and during the process, the other two artefacts are created and used. It is advised to first create a problem overview before the model is created, and creating the visualisation is difficult without

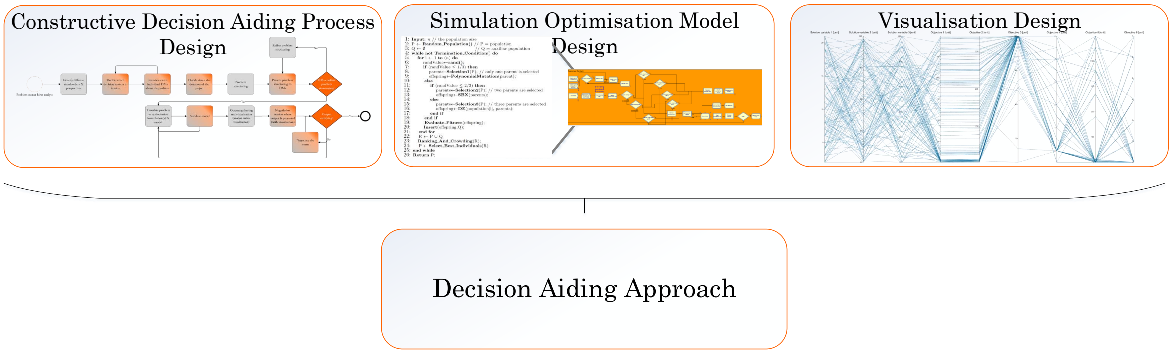


FIGURE 6.2: The designed decision aiding approach

the output of the model. But, iterations can take place, such as that during the creation of the SO model, one or more steps of the decision aiding process are repeated. Or, that after the creation of the visualisation the SO model or the problem formulation is revised.

The three artefacts depend on each other in essence that without a problem formulation, creating the model which properly represents the problem of the decision makers is difficult. Without the model, evaluating the possible solutions quantitatively is difficult. Without the results of the model, creating the visualisation is difficult since there is no data to put into the visualisation. Without the visualisation, it is difficult give meaning to the results for the decision makers to enable them to reach a decision. It is therefore believed that the decision aiding approach would not function properly when one of the elements is not present.

In addition, the three artefacts strengthen each other. When the decision aiding process is executed properly, this leads to a more accurate problem formulation and thus to a SO model which better represents the problem of the decision makers. In return, the model can function as a tool to communicate the problem formulation and enable the decision makers to find errors in the problem formulation. The visualisation helps to interpret the results of the optimisation model, and allows for a more thorough exploration of the results than without the visualisation, and allows to find errors in the SO model. In addition, the visualisation allows the decision makers to play with the results and in this way increases their involvement in the decision aiding process, which is important for the support for the selected solution. Last, the decision aiding process requires the involvement of the decision makers in the creation and validation of the SO model, which decreases the risk that the model is seen as a black box and could increase trust of the decision makers in the results of the SO model. It can be stated that by integrating the three design artefacts into one coherent decision aiding approach, the value of the approach is more than the value of the three single design artefacts together.

6.3 Constructive Decision Aiding and Many-Objective Optimisation: Combining the Soft and Hard Systems Paradigms

The combination of Many-Objective Optimisation and Constructive Decision Aiding might seem counter intuitive; MOO is a strongly quantitative method based on optimisation algorithms and constructive decision aiding assumes that there is no objective model of rationality and that there are many unknowns within the problem. Combining both methods can be seen as a conflict between the hard systems paradigm and the soft systems paradigm (Kirk, 1995). The combination is, however, less conflicting as it might seem at first sight. Because MOO allows for many objectives and is able to deal with conflicting objectives, it allows for the inclusion of multiple different perspectives in the problem formulation. Thus, the different stakeholders do not necessarily have to agree on which objectives are taken into account and no weights have to be divided amongst the objectives. Furthermore, using a simulation model as the model underlying the optimisation allows to incorporate uncertainty.

Nevertheless, some tension between both paradigms will probably be present. In the end, the basis for the SO model is a structured problem formulation, and even though this problem formulation can be revised and changed, the semi-structured problem must be transformed into a formal problem. Not every objective a decision maker might have can be incorporated in the optimisation, for example because it cannot be quantified. In addition, several assumptions have to be made to be able to capture reality in a model. It could be difficult for the different decision makers to agree upon these assumptions, and this is something the analyst should be aware off when creating the simulation model.

It is believed, however, that this combination between the hard and soft paradigm can be more valuable than when only one of the paradigms would be used. Using only the soft systems paradigm, it is hard to qualitatively substantiate the solutions and therefore they might be hard to compare. This might result in a sluggish process where stakeholders cannot reach a consensus due to the contested nature of the information in the process (De Bruijn, 2008). Using only the hard systems paradigm would consider that the problem formulation is given, which does not fully endorse the complexity which is present in the problem, namely that of a semi-structured problem. This might result in "correctly solving the wrong problem" (Tsoukiàs, 2007, 13). It is believed that the combination of both paradigms brings sufficient substance to the process to select a decision based on an analytical analysis while respecting the complexity of the problem under concern. By the shared creation of the problem overview and simulation model, and by allowing the decision makers to interact with the results, they can decide themselves which solution is acceptable. This is expected to increase the involvement of the decision makers in the process and the support for the selected solution.

It should be stated that the design of the constructive decision aiding process is mainly based on process management literature, while the context in which the decision aiding approach is used is an operational context. Even though this is taken into account during the design of the decision aiding process, this influences how the integration of the constructive decision aiding process and the optimisation model is done. As discussed in Section 1.2.5, in the operational context the type of problems dealt with can be characterised as semi-structured problems. In process management literature the problems dealt with are often ill-structured. Four specific differences are of influence for the integration:

1. **The motivation of the decision makers**; in the end all, decision makers are motivated to improve their business process together. Even though their perspectives differ, they share a certain goal, namely that of the organisation they work for. Therefore, the risk of decision makers exiting the process, blocking the decision making, or behaving strategically is much smaller than in a more strategic policy context. The decision makers might behave strategically, but within the boundaries of their common goal (De Bruijn et al., 2010).

2. **Hierarchical relations**; as explained in Section 3.5.1 in the operational context the relationships between the decision makers can be of a hierarchical nature. This results in the fact that a single decision maker can have the authority to force decisions upon other decision makers (De Bruijn et al., 2010).

3. **Focus on short and middle-long term**; the increase in performance of the business process is aimed to happen at a short term, or perhaps a middle long term. This differs from a strategic policy problem, where the focus in on the long term. This results in the fact that the process cannot have a very long duration and that there can be a point where a decision is forced to maintain progress in the process (Keen and Morton, 1978).

4. **Availability of data**; in an operational business context, often much data is gathered on a daily basis. This might make the creation of the evaluation model easier, since not all data has to be collected and negotiated during the process (Keen and Morton, 1978).

The integration between the decision aiding approach and the optimisation model is influenced by these differences. It is expected that it will be easier to come to a shared problem formulation and less iterations are necessary compared to an ill-structured problem, since more data is available and decision makers behave less strategically. This makes the creation of the evaluation model quicker and easier, and the model can be founded by the available data. But, it is of increased importance that the decision makers with the most authority can relate to the model, so it is important to validate the model thoroughly with them. Furthermore, it is expected that the negotiation session will take less time than when the problem was ill-structured, since the most powerful decision makers can steer the negotiation in their direction and since the decision makers do overlap in their objectives. Important to take into account for the solutions resulting from the model is that they have to be implemented on the short term. Solutions which might fulfil the preferences of the decision makers, but are not feasible to implement on the short term since constraints cannot be stretched on a short term, might be left out. This is something to consider for the analyst while creating the model, but also while presenting the model to the decision makers. It can be worth to point out some solutions which might not be feasible on the short term, but might be on the middle-long or long term if they have a large potential. On the other hand, the analyst should try to incorporate solutions which can be implemented on the short term.

6.4 Chapter Summary

The constructive decision aiding approach, the simulation optimisation model and the visualisation together form the decision aiding approach. The decision aiding process can be seen as the step by step guide in which the SO model and the visualisation are created and used. The three elements all need to be in place for the decision aiding approach to function properly and they strengthen each other. The decision aiding approach combines the soft and hard systems paradigm and it this way brings substance to the process while respecting the complexity of the semi-structured process. In the next chapter, Chapter 7 the working of the decision aiding approach is demonstrated in two cases at ING Bank.

7 Applying the Constructive Decision Aiding Approach

Two cases are used to demonstrate the application of the decision aiding approach. The two cases are both conducted at ING Bank Operational Services and are explained in this chapter. The first case is used to explore the application of the decision aiding approach on a real-life case. Based on this first case study, the decision aiding approach is slightly adapted before it is applied to the second case. The second case is used to validate the working of the decision aiding approach. The evaluation of the decision aiding approach is discussed in Chapter 8.

Topic of both cases is a customer contact process at ING Operational Services. Such processes handle a large part of the customer contact of ING, such as requests for the termination of a bank account, a complaint about a broken debit card, and so on. For ING Bank, these customer contact processes are important to maintain high service levels towards their customers. The customer contact processes are split up in different topic related departments, such as 'Payments and Savings', 'Loans', 'Bankruptcies' and so on. The work of a department can be divided in two main tasks: (1) answer incoming calls of customers and (2) process the requests of customers. These two tasks used to be executed by two separate teams: a customer contact team which handled all customer contacts and a back-office team which processed all requests. September 2015 ING decided to change this way of working due to the wish to deliver an end-to-end solution for its customers: the same team answers the phone and processes the request. This change prevents mistakes and delays due to less information transfers, which should lead to a better customer experience. Currently, every department is split up in several self-steering Customer Loyalty Teams (CLTs) which all handle a part of the incoming calls and requests end-to-end.

In practice this new way of working brings new dynamics in the processes. It requires the team members to be able to execute more and different kinds of tasks, and it requires the team members to be able to switch between those tasks. For example, where a team member used to only answer customer calls, (s)he now also needs to process this request in the systems of ING, or vice versa. Furthermore, when there suddenly is a peak in the number of calls, a team member who was busy processing requests should switch to answering calls to prevent long waiting times, and vice versa. Many departments struggle how to deal with these switching dynamics resulting in under performance of several departments on important KPIs. This revealed the need to gain more insights in the processes and to improve them. Many of the KPIs tend to be conflicting, so improving them is not straightforward. Furthermore, it is not clear how to different solution variables effect the KPIs exactly. In addition, the KPI's as used now only reflect one of the possible perspectives, while it is desired to take the influence into account on other objectives as well. It is expected that the decision aiding approach could help in making a decision.

7.1 Case Study I: The Service Desk Executors

The first case study is conducted at The Service Desk Executors (SDE, *In Dutch: Service Desk Nabestaanden*). The SDE handles all customer contacts and requests related to deceased customers. An example of such a request is the termination of a bank account of a deceased customer. Within the SDE there are two sub departments: (1) SDE-Regular and (2) SDE-Specials. These sub departments handle different kinds of request. 'Standard requests' are handled by SDE-Regular, whereas more 'complicated requests' are handled by SDE-Specials. An example of a complicated request is when a deceased customer has multiple products of ING, such as a bank account and a loan or a mortgage. Each sub department is led by a 'CLT Lead' and an 'Agile Coach'. A 'Super Circle Lead' oversees the performance of multiple departments, so for example not only SDE, but also 'Loans' and 'Bankruptcies'.

Each sub department has several Customer Loyalty Teams (CLTs). These operational teams consist out of ten employees and handle the customer contacts of the sub departments. A visual overview of the SDE is given in Figure 7.1. The CLTs handle customer contact end-to-end, both customer contact and customer requests. As explained in Section 2.2.3, the two tasks used to be executed by separate departments. This merge between the two former departments led to some indistinctness; when should an employee answer phone calls and when should an employee process requests? This indistinctness led to under performance of the CLTs on several KPIs. There is a need to get more insights in the different possibilities to organise the switching between customer contact and customer request and the effect this will have on different objectives, without having to try all different options in practise. In addition, also the influence of the capacity is seen as interesting, since it is believed that the department is currently having an under-capacity. With the use of MOO, the effect of the different options can be examined and a balance can be found between the different objectives.

This case study is focused on the sub department Regular, since Specials does not have a lot of customer contact which makes the switching between customer contact and customer requests less problematic.

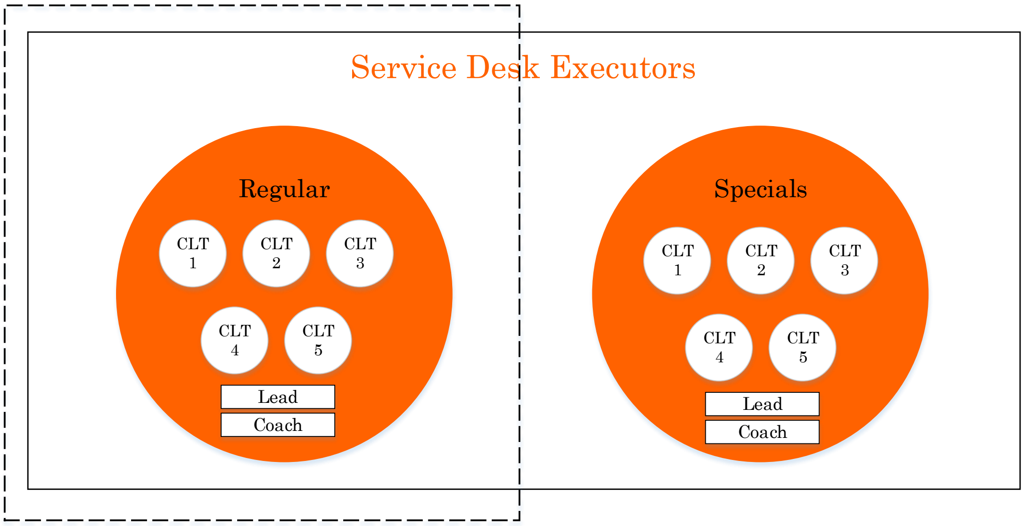


FIGURE 7.1: Schematic overview of the Service Desk Relatives

7.1.1 Application of the Decision Aiding Process

The decision aiding approach is applied to the case of SDE. This section will present an overview of how the decision aiding process was applied.

Step 1: Identify different stakeholders & perspectives. The decision aiding process commenced with a meeting together with the lead of SDE-Regular to get a first idea about the need she had and to explore the possibilities of the decision aiding. During this meeting the most important stakeholders / perspectives were identified, being: the customers, the employees and the cost perspective.

Step 2: Decide which decision makers to involve. After the first meeting, a decision is made who to involve during the process. Next to the lead of the department, the Super Circle Lead is invited, mainly since she has the authority to decide upon cost related issues. Furthermore, an employee is involved to articulate the opinion of the employees. Since the employees have to execute the processes, it is felt important to involve them from the beginning. It is decided to invite a surrogate decision maker to represent the customers, since it is considered undesirable to invite a real customer. It is decided, in consultation with the other stakeholders, that the 'Customer Journey Expert' of the team responsible for the SDE process is most equipped to fulfil this task. This results in a mixed level of the decision makers, some of the decision makers have positions in the middle-management of ING, and some are part of the operational core.

Step 3: Interviews with individual DMs about the problem. During two weeks the analyst set up individual interviews with the different involved stakeholders. The goal of the interviews was to get an overview of the problem the different decision makers experience, and the objectives they have and would like to have incorporated in the decision aiding approach.

Regarding the problem situation of the employees it was decided to have a short interview with one employee from each CLT instead of interviewing only one employee. Thus, six short interviews were conducted with employees: five with a member from each CLT, and one with the representative employee in the decision aiding process. The interviews resulted in an overview of the problem and the objectives the different perspectives have. It turned out that indeed the objectives were broader than the KPIs the department normally uses. The main problem was indistinctness on how to use the available resources and how to fill in some process variables to reach the desired objectives.

Step 4: Decide about the duration of the project. During the individual interviews it was examined how much resources, mainly time, the decision makers were willing to commit to the project, and when the project should be finished. This resulted in a time span for the project of two months, with a medium intensity.

Step 5: Problem structuring Based on the problem overview gathered from the individual interviews, the analyst created a problem overview. In this problem overview it was aimed to provide a concrete overview of all objectives and variables which influence the possible solutions, called the input variables. Not all objectives the decision makers had could be incorporated in the simulation model, since not all objectives could be quantified. This overview can be found in Table 7.1.

Step 6: Present problem structuring to DMs and ask for feedback/confirmation. The overview as created by the analyst in step 5 was presented to the decision makers for feedback. Based on this meeting, the overview was refined. An extra step in the problem structuring was to define metrics for the objective. The definition of the metrics was presented to the decision makers as well for feedback and refinement. An overview of the metrics can be found in Appendix E.

Step 7: Refine problem structuring. Based on the feedback of the decision makers in step 6 the problem structuring was refined. An example of such a refinement was for example what was meant with work pressure on the phone. At first, this was only seen as a high occupancy degree. However, it turned out that especially the presence of many customers in the waiting queue increased to pressure employees felt. This was changed in the problem overview. After the refinements had been processed, the new overview was presented again to the decision makers. They conformed the overview.

Step 8: Translate problem in optimisation formulation(s) & model. The translation of the problem to a formal model was a task mainly for the analyst. First, the processes which were subject of the decision making process were studied and simulated in a SO model. A detailed description of the model specification can be found in Appendix E. The creation of the model was mainly a task done by the analyst. Nevertheless, the decision makers were updated regularly and important decisions in the model were discussed with the decision makers.

Step 9: Validate the model. The SO model was evaluated in a session with all stakeholders. During this session all assumptions were made explicit, the input data was showed and the

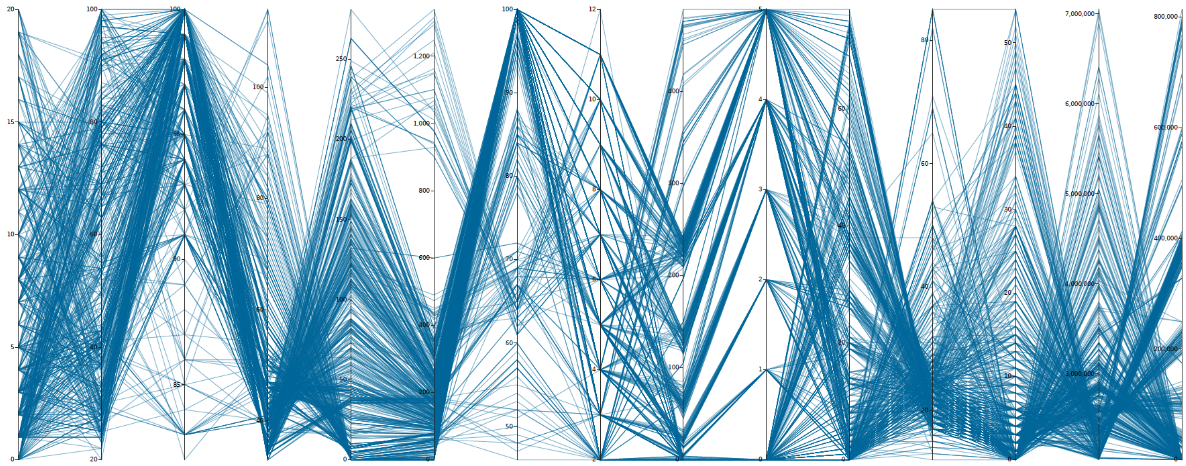
Perspective	Objective	Explanation
Customer	Low waiting time on the phone	The customer does not wish to wait a long time in the queue before an employee is available to answer
	Low processing time of requests	The customer does not wish to wait a long time before a request is processed
Employee	Little work pressure on the phone	The employee does not wish to have a very high time pressure when they are scheduled on customer contact, so they have enough time to process the phone call in the systems
	Little overtime	The employees do not wish to structurally work overtime
	Not too much switching	The employees does not wish to switch very often and for a very short amount of time
Cost	Low personnel cost	It is desired to keep the cost for fixed personnel within budget
	Low cost overtime	It is desired to keep the cost for overtime as low as possible
Design variables	Human capacity	Number of FTE, fixed and flexible, available
	Percentage customer time	The percentage the employee spends on customer related tasks
	Switching dynamics	When to switch employee from customer request to customer contact When to switch employee from customer contact to customer request

Table 7.1: Problem overview of the SDE case

working of the model was discussed. This again led to a refinement of the model. For example: where it was modelled that an employee decided to stop the switch from customer requests to customer contact when the number of customers in the call queue was below six, but this turned out to be guided by the waiting time on the phone (ASA). The refinements were made and confirmation was asked once all refinements were implemented.

Step 10: Output gathering and visualisation. After the model had been confirmed the optimisation was executed. The output was visualised in the designed interactive graph. The solution set contained about 600 possible solutions. The graph with the results can be found in Figure 7.2a.

Step 11: Negotiation session. Once the output was gathered the negotiation session took place. The meeting, which took about one hour, started off with a brief introduction about the goal of the meeting and an explanation of the type of visualisation used to present the results. The results were briefly presented to the decision makers, and the analyst presented a couple of possible solutions which were based on enlarging the contrasts between the different stakeholders. Subsequently the decision makers started to interactively explore the results. First the decision makers each explored the results individually to become familiar with the visualisation and to explore how the possible solutions affected their objectives. Next a collective discussion



(A) Overview of possible solutions (labels are removed due to confidentiality reasons)

Confidential

(B) Selected solution Case I (confidential)

Figure 7.2: Results of the SDN SO model

started, where all decision makers together tried to select a solution which was acceptable for all. A large screen was used to share the interactive visualisation, and the CLT lead was in charge of guiding the discussion and interactively changing the visualisation. It turned out that there was no solution possible which fulfilled all requirements of the stakeholders completely. A trade-off was made between several objectives, which resulted in the selection of a solution. The main concession was done on the objective ‘overtime for employees’. The selected solution is presented in Figure 7.2b. After the session the decision makers felt confident that the selected solution could help to increase the performance of their business process. There was, however, lack of time to explore possible solutions for the longer term. This could have been helpful since on a longer term, some of the constraints could be stretched more, which would have resulted in new possible solutions.

At the end of the meeting a short discussion took place on what to do with the results. It was decided to start an experiment with the switching dynamics which were selected to see whether this increased the performance on the objectives. Furthermore, it was decided that on the short term the performance on several objectives could be lower than the objective, since the model revealed that there was not enough capacity to reach all the objectives. On the middle long term, when more capacity becomes available, the performance goals will return to its original values.

A visual overview of the decision aiding approach can be found in Figure 7.4 at the end of this chapter.

7.1.2 Lessons Learned from Case Study I

Important aspect of the first case study was to explore the application of the decision aiding approach and use the lessons learned to fine tune the design before it is applied to the second case study. No big adjustments are made to maintain the comparability between the case studies to be able to use the second case for validation purposes. First, it was experienced how many iterations were necessary before the problem overview could be confirmed by the decision makers. This fits exactly with the characteristics of a complex, semi-structured problem, however, it was underestimated how much time this would require. Therefore, the lesson learned is to plan regularly meetings with all decision makers to discuss the problem overview right from the start, so the iterations can take place in a structured manner and the decision makers can provide feedback and ideas right from the beginning. The second lesson learned is that the validation session worked good to increase the involvement of the decision makers and to make very valuable refinements to the model. The third lesson learned was that the negotiation session was too short. Where there was enough time to understand the visualisation and select a short-term solution, the decision makers stated that they would have liked to also explore possible solutions for the longer term. In the long term, adjustments to the process could be made which could not be made on the short term, such as increasing the amount of FTE available for the process. This would provide the opportunity to score better on the objectives.

In addition, it would have been interesting to do a second negotiation session where the results of a new problem formulation were presented. By using a different problem formulation, different solutions might be discovered which do fulfil the needs of all decision makers (Kasprzyk et al., 2015). This could be very valuable in this case, since there was no solution possible which fulfilled all constraints of the decision makers. Due to time limitations it was not possible to explore this additional problem formulation.

For the second case study, it was decided to start from the very beginning with sharing the ideas of the analyst about the problem overview and do this regularly. Furthermore, it was decided to schedule more time, one and a half hour, for the negotiation session.

7.2 Case Study II: The Department of Distresses & Bankruptcies

The second case study is conducted at The Department of Distresses & Bankruptcies (DDB, *In Dutch: Afdeling Beslagen & Faillissementen*). This department processes all financial distresses and bankruptcies and maintains contact with the customers of ING and other legal parties who are affected by this. An example of a task which is executed by the DDB is to block a bank account of a customer upon which a bailiff laid a distress. It is important to block the account as fast as possible to mitigate the financial risk for the bank. The department is led by a 'CLT Lead' and an 'Agile Coach'. Since 90% of the work of the department is related to distresses, this process is the focus of this case study.

The work of the department is executed by five Customer Loyalty Teams (CLTs). These operational teams consist out of ten employees and handle the customer contacts; both answering calls and processing requests. An interesting dynamic in the work of DDB is a giant peak in inflow of requests at the end of each month. This peak can be explained by the fact that at that point in time most of the wages are paid out. This moment is a suitable moment for the bailiffs to lay a distress on an account, since this is only useful when the account has a positive balance. The work peak causes troubles for the performance of the department; during peak week more than 50 employees are required to do all the work, but outside peak week less capacity is needed. It is, however, unclear how to divide the capacity as efficient as possible given the objectives on risk minimisation and customer service. With the use of MOO, the effect of the different options regarding the capacity planning and process guidelines can be examined and a balance can be found between the different objectives.

7.2.1 Application of the Decision Aiding Process

The decision aiding approach is applied to the case of DDB as well. This section presents an overview of how the decision aiding approach was applied.

Step 1: Identify different stakeholders & perspectives. The decision aiding process commenced with a meeting together with the lead of DDB to get a first idea about the need he had and to explore the possibilities of the decision aiding. During this meeting the most important stakeholders / perspectives were identified, being: the customer, the financial risk for ING and the effectiveness of the capacity.
Step 2: Decide which decision makers to involve. After the first meeting, a decision is made who to involve during the process. It is decided to invite a surrogate decision maker to represent the customer perspective, since it is considered undesirable to invite a real customer as was the case in the first case study. The Super Circle Lead is invited since she has the authority to make decision about capacity. The lead of the department is responsible for the risk for ING and has the authority make decisions about risk related questions. In total three decision makers are involved in the process. All decision makers can be seen as part of the middle-management.
Step 3: Interviews with individual DMs about the problem. During one week the different involved stakeholders were interviewed by the analyst. The goal of these interviews was for the analyst to get an overview of the problem of each decision maker, and combine this in a problem overview. In conclusion two main problems were distinguished; indistinctness

about how to divide the capacity given the peak in workload, and indistinctness about switching dynamics between calls and requests.

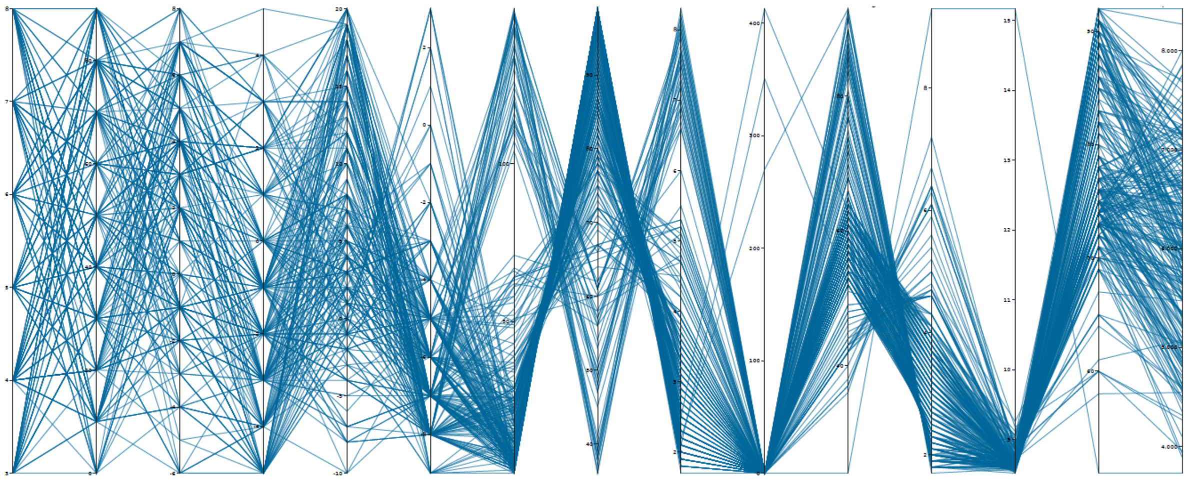
Step 4: Decide about the duration of the project. During the individual interviews it was examined how much resources, mainly time, the decision makers were willing to commit to the project, and when the project should be finished. Since the analyst already had experience from the first case study, it was expected that this project took less time. In addition, the CLT Lead had more time available for the project than in the first case study, so a duration of one month with a high intensity was selected.

Step 5: Problem structuring Based on the problem overview gathered from the individual interviews, the analyst created a more structured problem overview. As explained, this was done in a very iterative manner, by sharing the ideas from the analyst with the decision makers from the beginning. In this problem overview it was aimed to provide a concrete overview of all objectives and variables which influence the possible solutions, called the design variables. This overview can be found in Table 7.2.

Perspective	**Objective**	**Explanation**
Customer	Low waiting time on the phone	The customer does not wish to wait a long time in the queue before an employee is available to answer
	Low abandon rate	It is not desired that many customer end the call due to a long waiting time.
	Quick communication with the customer when account is blocked	It is desired that the customer gets informed quickly about his account being blocked.
	Work inventory at start peak week	It is desired to have no outstanding requests at the start of peak week
Risk	Fast screening of distresses	It is important to block the account as fast as possible to mitigate the financial risk for the bank.
Effectiveness of capacity	Peak week capacity	A suitable capacity during peak week
	Normal week capacity	A suitable capacity during the normal weeks
Design variables	Capacity peak week	Number of hours available during peak week
	Capacity normal week	Number of hours available during peak week
	Switching dynamics	When to switch employee from customer request to customer contact When to switch employee from customer contact to customer request

Table 7.2: Problem overview for the DDB case

Step 6: Present problem structuring to DMs and ask for feedback/confirmation. The overview as created by the analyst in step 5 was presented multiple times to the decision makers for feedback. The overview was presented in a meeting with all decision makers together, so everyone was informed about the problem perspectives of the other decision makers. Based on these meetings, the overview was refined. Once the problem overview was getting stable, the metrics were discussed as well. The definition of the metrics was presented to the decision makers for feedback and refinement. An overview of the metrics can be found in Appendix F.
Step 7: Refine problem structuring. Based on the feedback of the decision makers in step 6 the problem structuring was refined. An example of such a refinement was that it was felt important to make a distinction in the average lead time for screening between peak week and a normal week. Having only one metric for this variable would not present a proper indication, since in peak week the times are probably high and in a normal week low, which will result in an average which does not represent the true values. This was changed in the problem overview. After the refinements had been processed, the new overview was presented again to the decision makers. Again, an iteration took place, since it was considered interesting to split the capacity in hours for call and hours for requests. After a couple of iterations the decision makers conformed the overview.
Step 8: Translate problem in optimisation formulation(s) & model. The translation of the problem to a formal model was a task mainly for the analyst. Just as in the first case study a SO model was created in which the processes of the DDB were simulated. A detailed description of the model specification can be found in Appendix F. The decision makers were involved in the creation of the model since all the data and assumptions were checked with them.
Step 9: Validate the model. The SO model was evaluated in a session with all stakeholders. During this session all assumptions were made explicit, the input data was showed and the working of the model was discussed. This again led to a refinement of the model. For example: the moment when peak week ended was changed. The refinements were made and confirmation was asked once all refinements were implemented.
Step 10: Output gathering and visualisation. Once the model was refined based on the visualisation session, the analyst ran the optimisation and gathered the output. It turned out that the solution set was very large; more than 5000 solutions. Since this amount was too much to work with in the visualisation, the analyst made a selection of about 500 solutions. This solution set still represented a diverse set, but many unrealistic solutions were cut out. An example of an unrealistic solution was a solution where there were over a thousand hours of work inventory at the start of peak week. Since the objective was to have zero hours, having over a thousand hours would not be acceptable for the stakeholders. The remaining solution set was visualised in the designed graph, which can be seen in Figure 7.3a.
Step 11: Negotiation session. Once the output was gathered the negotiation session took place. The meeting, which took about one hour and a half, had the same set up as the meeting of case study I. The analyst started off with a brief introduction about the goal of the meeting and



(A) Overview of possible solutions (labels are removed due to confidentiality reasons)

Confidential

(B) Selected solution Case II (confidential)

Figure 7.3: Results of the BF SO model

an explanation of the type of visualisation which was used to present the results. The results were briefly presented to the decision makers, and the analyst presented a couple of possible solutions which were based on enlarging the contrasts between the different stakeholders. Subsequently the decision makers started to interactively explore the results. First the decision makers each explored the results individually to become familiar with the visualisation and to explore how the possible solutions affected their objectives. One of the decision makers needed a bit more time to understand the visualisation, but after about 15 minutes everyone was interacting with the graph. Once everyone understood the visualisation and made up their mind about their own preferences, the collective discussion started, where all decision makers together tried to select a solution which was acceptable for all. A large screen was used to share the interactive visualisation, and the CLT lead was in charge of guiding the discussion and interactively changing the visualisation. It turned out that there was no solution possible which fulfilled all requirements of the stakeholders completely, but quite some which were acceptable for everyone. The results confirmed a trend the decision makers experienced for a while, but they were never able to quantify this feeling. Three possible solutions remained, where the main compromising factor was the capacity. The decision makers had some difficulties comparing the three remaining solutions, but in the end were able to select a solution based on formulating which objective was most important and selecting the solution which scored best on that objective. The resulting solution is presented in Figure 7.3b.

The decision makers decided to try to make a switch in capacity, to have more capacity within the peak week and less capacity outside peak week. Since other departments of ING do comparable work, it was decided to investigate the possibility to teach people from other departments how to do the most common work during peak week, and to school the employees of DDB in the skills of other departments, so they could be of value for other departments outside peak week.

A visual overview of the decision aiding approach can be found in Figure 7.5 at the end of this chapter.

7.2.2 Reflection on Design Refinements

It was experienced that involving the decision makers from the beginning in creating the problem overview worked well to keep the speed in the process and to start refining the problem overview quickly. Furthermore, the negotiation session was with one hour and a half long enough for the decision makers to come to their conclusions. There was enough time to discuss the current situation, but also to look forward to the longer term and to discuss the implementation of the selected solution. However, during the negotiation session some new questions popped up which could not be answered during the session. This was not caused by time limitations, but by the problem formulation which was used. It would have been nice if another session could take place to discuss that questions, or ideally, if a new optimisation run could have been done during the session to be able to answer that question. Due to time constraints of this research, an additional session was not possible. Due to computational limitations, it was not possible to run a new formulation during the same session.

7.3 Chapter Summary

This chapter illustrated how the decision aiding approach can be applied to two real-life cases at ING bank. Based on the first case, the design is refined and validated in the second case study. In both cases, the decision aiding approach was successfully applied. The value of the application is evaluated in the next chapter, Chapter 8.

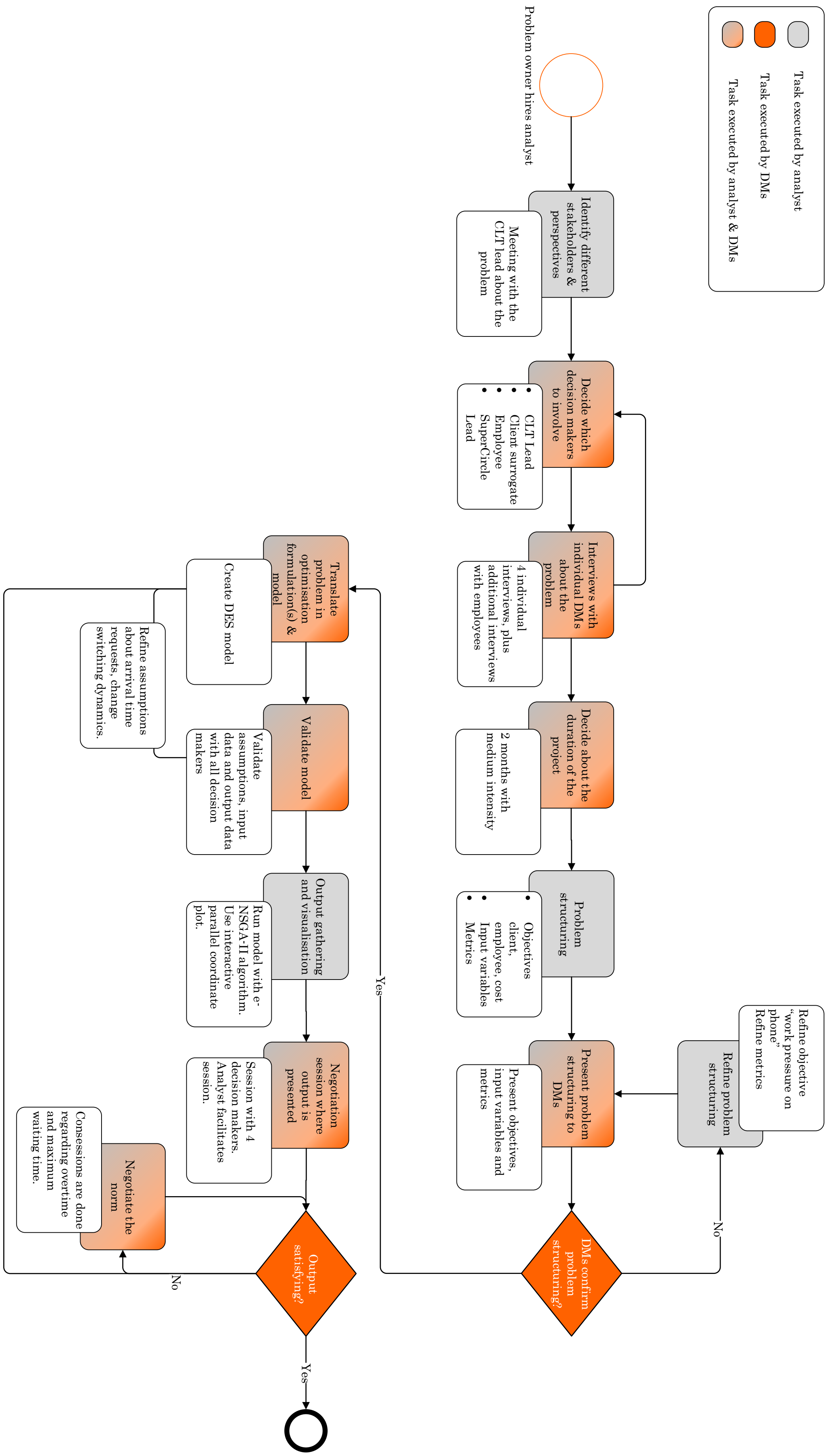


Figure 7.4: Decision aiding approach applied to Case Study I

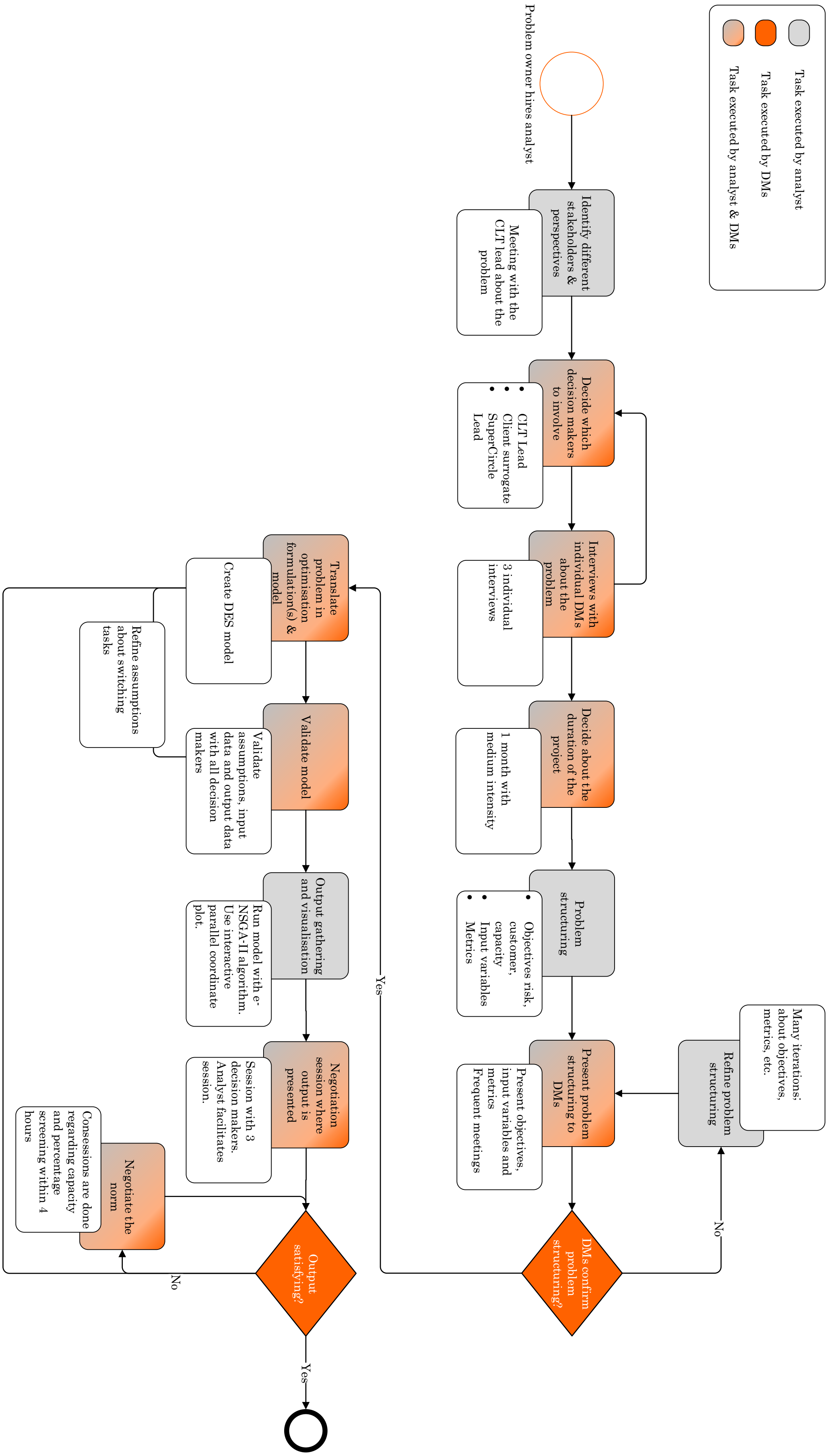


Figure 7.5: Decision aiding approach applied to Case Study II

8 | Results of the Evaluation

This chapter elaborates on the results of the evaluation of the designed decision aiding approach. Where Chapter 7 demonstrated the application of the decision aiding approach in two cases, this chapter evaluates the application of the approach. The evaluation is, as explained in Chapter 2 divided in five parts: (1) the selection of a Pareto optimal solution, (2) the increase in awareness about business process improvement possibilities, (3) strengths and weaknesses of the overall and specific parts of the decision aiding process, (4) the efficacy of the visualisation and (5) the utility of the decision aiding approach in an operational business improvement project.

Note: This chapter uses quotes distracted from the evaluation interviews to support the findings. The quotes used in this chapter are translated to English. The original quotes, in Dutch, can be found in Appendix G, based on the interviewee number and line numbers of the quote. For example: (I1:21-25) corresponds to Interviewee 1, line 21 till 25.

8.1 The Selection of a Pareto Optimal Solution

As discussed in Chapter 2 and 3 one of the main objectives of a decision aiding approach is to aid the decision makers to come to a decision. Applied to this research, the objective is to aid the decision makers to select a Pareto optimal solution from the solution set. This part of the evaluation is thus concerned with the question: did the approach aid the decision makers to select a Pareto optimal solution? This is seen as a relevant aspect to evaluate the decision aiding approach upon, since a decision is often needed to effect the insights gained and to obtain concrete results in for example an improved performance of the business process.

In both cases the decision makers were able to select a solution. This solution was one of the Pareto optimal solutions which resulted from the output of the optimisation. The selected solution of case study I is presented in Figure 7.2b and the selected solution of case study II is presented in Figure 7.3b.

Nevertheless, coming to a decision was not straightforward. In both cases trade-offs had to be made to come to a decision, especially in the first case study. As I3 stated during the evaluation interview:

"I ran into the fact that it was possible to have all my constraints secured, but that in that case others had to make concessions. There was no possibility where everyone was 100% satisfied. This insight was an eye opener to me." (I3:214-218)

After a discussion about which trade-offs were preferred, a solution could be selected in the end. During the interviews it was asked how this decision took place. As one of the interviewees explained clearly:

"In the end we all have a common goal: serving our customers to our best abilities. So, by starting off with selecting what we thought was most important, the preferences of the customers, and subsequently making choices on how to fulfil the other objectives as best as possible given the constraints the customer requirements implied, we were able to make a decision which was acceptable for everyone." (I3:220-223)

The decision was thus made by first finding a common goal of all decision makers, and adjusting the remaining objectives to the constraints of the common goal. In the second case, there were multiple solutions remaining after the constraints were filled in. After a comparison of the three remaining solutions, one was selected based on what the decision makers ought to be the most important objective.

8.2 The Increase in Awareness About Business Process Improvement Possibilities

The second aspect of the objective of the designed decision aiding approach is to increase the awareness of the decision makers about business process improvement possibilities. Chapter 2 explained what this awareness is and why this is seen as a relevant objective. In short: awareness can be seen as the main precursor to decision making, so a decision is made based on the perception of the decision maker of the current situation. It is presumed that a higher awareness leads to a better decision (Endsley, 1995). Thus, in addition to the fact that the decision aiding approach aims that the decision makers make a decision, it also aims that this is a better decision than when the decision aiding approach did not take place. Since this is unfortunately hard to evaluate, being not possible to run two projects parallel with and without the decision aiding approach, the situation awareness is measured during the approach. How this is measured is explained in Section 2.2.4.

The decision makers filled in their preferences on the solution variables and the objectives three times during the process: after the problem formulation, after they individually explored the results and after they selected a solution. It is checked whether the preferences of the decision makers changed over time. This change can indicate a change in awareness. For all decision makers, their preferences changed between the moment after the problem formulation and the moment after they individually explored the results. This change was caused by two insights. First, often given the preferences of the decision maker, there was no solution possible; given the results from the SO model, no solution could fulfil all preferences. In addition, a reason five out of seven decision makers stated was that they changed their preferences due to an understanding in how the objectives were related to each other. For example: since there was no solution which fulfilled all preferences, a concession was done on a less important preference to fulfil the most important preferences.

The change in preferences between the moment the decision makers explored the results individually and the moment they explored the results collectively differed in the two case studies. In the first case study, all decision makers again changed their preferences after the collective discussion. Main reason for this change was insight in the preferences of other decision makers. The solutions which the decision makers individually selected were not acceptable for the other stakeholders. Several concessions were made which resulted in a solution which was not the first choice of all decision makers, but was an alternative everyone could agree upon. In the second case study, none of the decision makers changed their preference between the moment the decision makers explored the results individually and the moment they explored the results collectively. This was explained by the decision makers since there were multiple solutions possible within the preferences, so the best solution out of the remaining three solutions could be selected.

In addition to the changes in preference, the decision makers were asked to rate their awareness at different moments during the process. The results of this rating can be seen in Table 8.1, where a + indicates that self-rated awareness increased, a +/- indicates that the was no change visible and a - indicates a self-rated decrease in awareness. A few insights are highlighted. First, the decision makers did not feel that they became more aware of the different alternatives they had to improve their process. They felt, however, that their awareness about the dependencies between the objectives (the trade-offs) did increase. During the evaluation interview, it was asked how they felt this did increase. One of the decision makers stated:

> *"I was aware of the dependencies in general, but this model gave me more information on how much they depended on each other and what the quantitative effect is of one objective on the other."* (I11:772-773)

The decision makers also rated an increase in the knowledge they had about the preferences of other decision makers. The main increase in this variable was seen after they collectively discussed the results. The increase was stronger in the first case study than in the second case study. This could be explained by the fact that in the first case it was harder to find a solution, so more discussion was needed to come to a solution. During the discussion, most of the preferences are discussed.

Most of the decision makers did not report an increase in the awareness about how the solutions effected the objectives. This can be explained by the fact that the decision makers mainly approached the results from the objectives perspective. In other words: they filled in their preferences and checked which solution could reach their preferences. When they would have approached the results from the solutions, starting off with making a choice in solution variables and checking how this influenced their objectives, this awareness might have increased. However, during the evaluation interviews, it was stated that this was not the goal of most decision makers. They mainly used the results to see how they should adjust their process to reach their objectives.

Last, the question was asked how certain the decision makers were about their preferences and how much margin there was for negotiation. Both exploring the results individually and discussing the results collectively did not make the decision makers less certain of their preferences. Most decision makers remained at the same level of certainty and some decision makers became more certain. This last effect was mainly present after the collective discussion. Exploring the results individually did increase the margin there was for negotiation, especially in the first case study.

Case I: SDE						
	Margin for negotiation	**Confidence**	**Awareness possible solutions**	**Awareness effect possible solutions**	**Awareness trade-offs**	**Awareness preferences other DMs**
After exploring individually	+	+/-	+/-	+/-	+	+/-
After the collective discussion		+	+/-	+	+	+
Case II: DDB						
	Margin for negotiation	**Confidence**	**Awareness possible solutions**	**Awareness effect possible solutions**	**Awareness trade-offs**	**Awareness preferences other DMs**
After exploring individually	+	+/-	+/-	+/-	+	+/-
After the collective discussion		+	+/-	+/-	+	+

Table 8.1: Results of change in self-rated awareness

8.3 The Strengths and Weaknesses of the Overall and Specific Parts of the Decision Aiding Approach

In addition to evaluating the decision aiding approach on its objective, the decision aiding approach in general is evaluated to identify strengths and weaknesses. Those points can be used to further improve and apply the decision aiding approach and are thus seen as very relevant information to gather. The evaluation of the strengths and weaknesses is divided into six aspects, which are all addressed during the evaluation interviews and these six points are used to structure this part of the evaluation results as well.

8.3.1 Involvement in the Overall Process

All decisions makers stated that they felt involved during the decision aiding process, mainly at the start of the project during the knowledge gathering and problem structuring, and at the end of the process with the model validation and the negotiation session. The decision makers did not feel very much involved in the creation of the model. Involvement in that aspect of the approach was not seen as a crucial point by the decision makers. As I1 stated:

"It would have been nice to be more involved during the creation of the simulation model, however, due to my span of control there was not much time available for this. It would have been nice for my own understanding, but it was not crucial for the project to succeed." (I1:23-25)

On the other hand, the operational excellence consultant stated:

"To create a 'buy in' effect and to increase the enthusiasm for the project, it might have helped to involve the decision makers more in the creation of the model. Even though it might be hard to ask for more time, this would probably increase their expectations about the project which results in that they easier make time during the rest of the process. In addition, it could also increase support for and implementation of the solution." (I6:457-460)

8.3.2 Formulating the Problem

In general the decision makers felt strongly involved in the problem formulation. The decision makers appreciated that a lot of time was available for this step, since this provided them with the possibility to rethink their ideas about the problem. Furthermore, it was considered valuable for the comprehensiveness of the problem that the opinion of different stakeholders was included in the formulation. It was felt that this made it easier for the solution to be understood and accepted by all parties involved.

"It was valuable that you [the analyst] spoke to multiple employees of the SDE department and took the time to incorporate our view in the problem formulation. This took some additional

time, but makes it a lot easier later on to explain the selected solution to the employees and increases the support." (I2:129-131)

"I liked the fact that you interviewed everyone individually about the problem they experienced. I have the feeling that you truly incorporated my input, and if it was not possible to incorporate something, you [the analyst] explained it clearly to me. That is highly appreciated." (I3:190-193)

8.3.3 Creating and Validating the Model

The decision makers did not feel very much involved in the model creation, but did feel that it was valuable to validate the model together with all decision makers. The value of the validation was to get an idea about the model and to ensure that it represented reality in the best possible way. On the other hand, it was seen as a means to ensure that all decision makers are on the same page about the model, which makes the negotiation session easier.

"During the validation session my idea about the model became more clear and I started to understand the working of such a model. This piece of background information helped me to interpret the results. I would definitely recommend the validation session to everybody involved." (I9:611-614)

8.3.4 The Negotiation Session

In both case studies the negotiation session was seen as very valuable by all the decision makers. One of the decision makers stated:

"The interactiveness of the results worked well in the session with all stakeholders. This made it possible to let us play with the results and to let us decide ourselves which solution is the best for us. This truly revealed some of the inter-dependencies between the different objectives." (I1:36-38)

So, by allowing the decision makers to play with the results themselves, they realised how much their objectives were related and how much their decision impacted one another. In addition to this, multiple decision makers mentioned the value it had that they were able to draw conclusions themselves, instead of an analyst presenting the conclusions to them.

"We experienced ourselves that what we wanted was not possible. To me, this was way more valuable than if you [the analyst] would have told me that something was not possible." (I3:217-218)

A point of improvement in the negotiation session was the duration of the session. The session of the first case study took place in one hour. Some of the decision makers mentioned that this was long enough to come to a conclusion, but that they would have gained more insights when the session took slightly longer.

"It would have been nice if we did not only agree on the solution which we want to use now, but also where we want to be next year. During the session, there was only time for the first point. On short term, some constraints are fixed, but on the long term it might be possible to broaden them. Looking to the future, it would have been nice if we could have explored possibilities for further improvements and what alternatives are possible to perform even better." (I4:327-330)

In the second case study, in which the session lasted one hour and a half, there were no complaints and the decision makers were able to finish in time. This was, however, also a less intensive discussion since there were three solutions which were all acceptable for the decision makers. It is uncertain whether one and a half hour would have been enough time in the first case.

8.3.5 Confidence in the Results

All decision makers articulated that they trusted the results, or at least saw them as a strong indication about what could happen. Due to the fact that all decision makers had been present in the validation session, everyone was aware of the assumptions in the model. One of the interviewees nicely explained how this impacted her trust in the results:

"Because I was present at the validation session I knew what the model could and could not do. One main assumption is of course that all employees do what they have to do, and not for example take a extraordinary long break. Of course, the results never truly reflect reality 100% but I believe they are a strong indication of what will happen when we make a certain choice." (I2:144:147).

8.3.6 Balance Impact and Time of the Decision Makers

In a business environment time is a scarce resource and everyone wants to work efficiently and effectively. Therefore, the approach aimed to not ask for a large time investment of the decision makers. All decision makers felt that the approach did not asked for much time; about an hour per week. It should be noted that this small time investment of the decision makers was possible because there was another project of the department of operational excellence running at the same time. This saved a lot of time since data already was available and meetings could be combined. Nevertheless, it was felt by most of the decision makers that it would have been acceptable to invest more in time in such a project when this is necessary.

> *"I'm always trying to find a balance between meetings I must attend to improve the results of the project, and meetings which I do not necessarily have to attend. [...] I would not mind spending some more time on such a project when this would have been necessary now I know how valuable these results are."* (I3:195-196, 236-238)

A point of improvement on the impact of the approach multiple decision makers and one of the operational excellence consultants mentioned was that the decision aiding approach was very focused on generating new insights and making a decision, but not on the implementation of the selected solution. This could be the result of the scope of this research, where the implementation of the solution is out of scope. However, to ensure the effectiveness of the decision aiding approach the implementation phase is crucial, and thus attention should be awarded to this aspect during the decision aiding approach. Since the decision aiding approach probably will result in some changes in the work processes of employees, it is urged by one of the CLT leads to stronger involve the operational employees in the decision aiding approach; not only in the problem formulation phase, but also in later stages of the approach. The visualisation can for example be used as a means to convince employees that the right decision is made.

Considering the value of the approach, all decision makers are positive. Especially for fellow departments which struggle with the same conflict between objectives, the approach is seen as valuable and recommended to use.

8.4 The Efficacy of the Visualisation

The visualisation is a crucial part of the decision aiding approach, since it gives meaning to the results coming from the SO model. Evaluating the visualisation with the users can thus provide us with valuable feedback to further improve the visualisation to make it better suitable for the task the users have to fulfil, or to make it more clear or user friendly. The evaluation of the visualisation is twofold: observations by the analyst of the users while using the visualisation, and questions during the evaluation interviews. The information gathered by the evaluation is structured along the levels of the evaluation framework of Munzner (2009).

8.4.1 Domain Problem Characterisation

The domain the visualisation is used in is an improvement project of an operational business process of a customer contact centre. This layer of the evaluation is concerned with questions such as: "Did the visualisation help to select a business process improvement solution?". Furthermore, this part of the evaluation is focused on the match between the complexity of the graph and the users.

None of the decision makers had experience working with a parallel coordinate plot, or another type of plot in which they could select preferences on objectives and solutions. The first reaction, both observed and stated by the decision makers during the evaluation interview was: 'wow'. However, all decision makers told that after a good explanation of what was shown in the graph and how to use it, they understood the graph quite quickly. This was confirmed by the observations; after about five minutes all decision makers were working with the graph to find a solution. Nevertheless, using the graph without any explanation would be complicated, so a proper explanation is required to be able to quickly understand the graph.

"At first sight I thought: "wow, this is very complicated". The graph looked like a weaving work to me. But, after having a good explanation and trying myself to select a couple of things, I understood the working quite quickly. By selecting ranges on the objectives, the graph becomes less complex. But, you cannot share this graph with everyone without a proper explanation" (I2:174-178)

The visualisation worked well to support the selection of a solution. The combination of selecting ranges on the different axes, and the disappearance of the data points which did not fit with that preferences worked intuitively and quick according to the decision makers. During the negotiation session it was noticed by the analyst that it worked well to first let the decision makers experiment with the graph individually. By doing this the decision makers quickly understood the working of the graph.

In addition to using the visualisation to select a solution, one of the decision makers stated that the visualisation was very valuable to her to convince people about the decisions which are made. So, the graph can not only be used to select a solution, but also to communicate this solution and convince people of the value of this solution.

8.4.2 Data/Operation Abstraction

The data/operation abstraction level is focused on whether the information in the visualisation was valuable for the users in selecting a solution. Questions are for example: "Did you miss any information to make a decision" and "What are the main insights you got from the visualisation?".

Most decision makers declared that the visualisation especially gave them insights in the dependencies between the objectives. In addition, these dependencies provided them with knowledge about the consequences of their decisions. By letting them free to select objectives in their own sequence, they started thinking about what truly was most important for them. Furthermore, they started to project their ideal situation to reality, and adjust their ideals to reality:

"I liked the fact that I had the opportunity to think which objectives are most important to me. Making different trade-offs between objectives resulted in different, maybe more desired, possible solutions. This connects the ideal world to reality, where not only my opinion matters, but also the opinion of others." (I3: 288-292).

More about the information the decision makers distracted from the graph is described in Section 8.2. Most decision makers declared that they did not miss any information to come to a decision. Nevertheless, one of the decision makers did express his appreciation for the fact that a short list with explanations of the labels from the axes was provided during the negotiation session. This did help him in understanding correctly what was meant by the labelling. A concern is raised by one of the decision makers and is related to the information on which a solution is selected:

"I found it hard to compare the remaining solutions. Sometimes it is not clear how they differ and how much exactly. Maybe the graph can support this better by showing their values in a different way?" (I10:718-719)

This concern is seen as an important remark in the working of the visualisation. Since the main task of the decision makers is to select a solution, this should be supported as best as possible. The current visualisation does not support the decision makers if a situation happens where the decision makers filled in their preferences and want to compare the remaining options. This can be done by showing the values of the solutions in the graph or in a separate table. Furthermore, one of the decision makers mentioned that it would be valuable to be able to fill in weights when such a situation happens. For example, when there were only three alternatives left, that it was possible to assign weights to the objectives and see which solution scored best based on the weights.

The second concern is one observed by the analyst and is related to selecting a solution as well, but about the opposite scenario: what if there is no solution possible given the constraints of the decision makers? The decision makers must start a negotiation about their constraints to come to possible solutions, but how to approach this negotiation? This situation occurred in the first case. The decision makers started negotiating about one of the objectives which they considered to be constraining, but this was based on their feeling. It did happen that after a discussion the constraint was adjusted, but that this change did not result in additional possible solutions. Therefore, it would be valuable if the visualisation would support this type of situation by showing for example solutions which are close to the given constraints. By showing these solutions it becomes more clear for the decision makers which constraint is blocking additional solutions and the discussion can be targeted on this constraint. This could result in a more effective discussion during the negotiation session.

8.4.3 Encoding/Interaction Techniques

The encoding/interaction level is concerned with how the information is presented to the users and how they can manipulate the view. Information is gathered about the clearness of the visual encoding and about the usability of the interaction techniques. In addition it is asked whether the users would like to see something in a different way the next time.

Most of the decision makers were satisfied with the visual encoding and interaction techniques of the graph. Nevertheless, several points of improvement were mentioned. To start with, in both case studies the graph was very wide. It was possible to show the entire graph on the screen, but the decision makers first had to adjust their zooming level of the browser. It would be more convenient if this was not necessary and the zooming level is adjusted automatically.

Furthermore, the labels of the axes could have been more appealing. The labels were horizontally placed next to each other, with resulted in a clutter of text when the labels were too long. Alternatively, the unit of the axis variable might have been placed one line under the label itself.

Concerning the labelling of the selection brushes some confusion existed. As one of the decision makers stated:

> *"The label showed a different value than I thought I selected. For example: I thought I selected the range 0 - 30, but the label showed 0 - 6. This was confusing to me."* (I4:376-378)

This type of visual feedback after the selection is based on the values of the data points which the decision makers did select. The upper label shows the value of the highest data point in range, the lower label shows the value of the lowest data point in range on that particular axis. It could be the case that the highest data point in range is located at the bottom of the selection range, resulting in a label which is much lower than the range which is selected. This confusion was also observed by the analyst during the negotiation sessions.

In the first case study, some indistinctness was observed regarding the selection on one particular axis: the TITO value [%]. Were multiple of the decision makers thought they selected only solutions which scored 100% on that axis, in reality they selected all solutions, ranging from the lowest value till 100%. During the evaluation interviews it was asked where this confusion came from. This resulted in the insight that this axis was the only axis in the graph where the value had to be maximised. All other axes were aimed to minimise. Therefore, on every axis, the decision makers started with selecting their preferences at the bottom, till the value which they thought was acceptable. Since the acceptable value at TITO was 100% for most decision makers, they ended up selecting the whole axis. This might have been a flaw in the explanation of the graph, since this was not clearly stated.

8.5 The Value of the Decision Aiding Approach in an Operational Business Context

As explained in Chapter 1 MOO with a posteriori decision analysis is not applied that often in an operational business context. Evaluating the value of the application of the decision aiding approach in such a context can provide us with valuable insights on the utility of the approach in such a context and indicate possible points for improvements. The evaluation is structured along five points: the utility of the approach in an operational business improvement project, the benefits of the SO model in comparison to a classical simulation study, the type of problem where the decision aiding approach is considered relevant, drawbacks of the decision aiding approach, and suggestions for improvement.

8.5.1 The Utility of the Decision Aiding Approach in an Operational Business Improvement Project

The main utility of the decision aiding approach which is seen by the decision makers and by the department of operational excellence is the ability to formulate performance goals in a more precise way, and to adjust the business process in a way which allows for the realisation of those goals. Since the goals can be formulated fact-based, there is a larger incentive to strive for those goals, compared to when the goals were formulated based on assumptions. One of the department leads stated:

"This type of model can help us, the different CLT leads of ING Operational Services, to formulate our goals for the coming year based on data instead of based on our feeling and experience. At the moment, we never know for sure whether a goal is realistic, and how to change our process to reach the goals." (I1:82-85)

This is endorsed by one of the managers of the operational excellence department:

"It is valuable since it allows the people leading the operational services to come closer to reaching their goals, by allowing them to formulate them fact-based and more precise" (I5:393-394)

The way of making decisions based on facts instead of gut feeling is seen as an asset in a self-steering organisation such as ING. Especially decisions which are made by self-steering teams, it is urged by one of the CLT leads (I1) that this is done based on facts.

Furthermore, the decision aiding approach can lead to more support for the decision, which is seen as very valuable. Since multiple different objectives can be taken into account, different people within the organisation felt involved. The employees of the department were allowed to play with the results themselves, and make the decision themselves. Even though the department of operational excellence has less control in this way, the expected increase in support is seen as very valuable.

It is stated by multiple decision makers and by operational excellence consultants that getting such a complete overview of possible solutions, their effects of the objective and the trade-offs amongst the objectives is hard with other methods. Other methods only allow for the investigation of one or a couple of solutions, or allow only one or a limited number of objectives. In addition, experimenting in real-life is very time consuming, so would not be a feasible alternative as well.

"I do not see another way in which we could get the same insights, except for trying different solutions with trial and error. This costs a lot of time and energy, and often does not lead to the right solution. This is much more effective and efficient." (I11:775-777)

8.5.2 Benefits of the Simulation Optimisation Study in Comparison to a Classical Simulation Study

The main benefit of a SO study in comparison to a classical simulation study which is experienced by the operational excellence consultants is the fact that the SO model provides the opportunity to calculate the effect of many different solutions, in contrast to a classical simulation study where only a couple of scenarios can be investigated. This is seen as an advantage, since often it is very hard to come up with a good selection of scenarios. SO provides the opportunity to investigate all different combinations of solutions and only selects the combinations which are Pareto optimal given the objectives. This last aspect is also seen as valuable, since it is not possible with a classical simulation study to determine whether a solution is Pareto optimal.

"The big advantage of a SO study is that you select only the Pareto optimal solutions. In a classical simulation study, you never know if this is the case. Using optimisation mitigates that risk." (I7:545-537)

Another advantage which is pointed out is the possibility to answer a question such as 'What should I do to increase my performance on objective X - Y?' instead of 'What happens if I change this factor in my process?'. According to one of the operational excellence consultants, the first question is posted more frequently. This first question can be answered more effectively with a SO study, since many different combinations of solutions can be investigated.

Furthermore, one of the consultants expects that, by presenting the decision makers many possible solutions, the chances are higher that there is an alternative which all stakeholders can agree upon, compared to a situation in which only three till five scenarios are investigated.

"Since the decision makers can choose from so many different possibilities, the possibility to find a solution which is acceptable for everyone is larger." (I8:573-574)

8.5.3 Relevant Problems for the Decision Aiding Approach

Since the decision aiding approach is considered valuable to use in an operational business context, it is important to determine which type of problems are suitable to solve using the decision aiding approach. To the statement 'I would use such a decision aiding approach with MOO in every project' the consultants unanimously answered: 'No, not in every project. That depends on the context of the problem.'. Projects which are suitable for this approach are considered projects focused on formulating performance objectives and improving the process to reach those objectives (called Operational Management projects, OM). It is considered to be especially relevant when there are many performance objectives, or conflicting objectives, or a combination of both and it is not clear how to reach the objectives. The decision aiding approach is especially relevant since in this case it is hard to research this using the standard tools of the operational excellence department.

"I see applications of this method especially in OM projects. Using this method we can create insight in the trade-offs between the objectives, formulate achievable goals and optimise the process for these goals." (I6:503-507)

It is not considered relevant to use the decision aiding approach when there are very little alternatives possible. In that case, more simple methods, such as a scenario analysis in MS Excel, would be sufficient and cost less time. An additional constraint posed for the use of SO is the availability of data. When there is little data available, it would require a large time investment to acquire this. The question should be asked if it is possible to create a simulation model without spending too much time in gathering data.

An additional type of project which could be suitable for such an approach are projects with a lot of uncertainty. An example of such a project is the introduction of a new contact channel for customers, where it is completely unknown how much additional inflow of customer contact traffic this will generate. It would be possible to explore solutions over time given the uncertainty, and evaluate this on objectives.

8.5.4 Drawbacks of the Decision Aiding Approach

Even though the approach is seen as valuable, also some drawbacks are seen. First, using simulation is a time intensive approach, and it should always be asked whether the question cannot be answered using more simple tools. Second, the more complex the method, the higher the risk the method becomes a black box for the decision makers, which could impact the trust they have in the results. In addition, the large amount of possible solutions can be beneficial, but can also slow down the decision making process since there is such a large amount of information for the decision makers.

"I see a risk of creating an overload in alternatives, which can make it harder to select one alternative and slow down the decision making. Of course, the knowledge gathered by playing with the results is valuable, but in the end you will only accomplish results when a decision is made and the solution is implemented." (I5:442-445)

8.5.5 Suggestions for Improvement for an Operation Business Context Perspective

In general, there is enthusiasm for the decision aiding approach. However, two main improvements are indicated which can make the approach more valuable in an operation business context. First, it is considered relevant to pay more attention to the implementation of the solution. This can be done both during the decision aiding approach, by involving more employees of the operational processes, and after the decision is made, by helping with the implementation of the solution. The decision aiding approach as designed in this research ends with the decision, but that is not where a business process improvement project ends:

"After the decision, we have to implement the solution, measure whether this leads to the expected performance and if necessary, refine the solution. This final part is crucial for the success of the project." (I6:507-509)

In addition, it would be valuable if the model is easy to change. The business processes are subject of constant improvements and changes at many different aspects. It would be a waste of value if the model is outdated quickly after it was made. Therefore, it would be an improvement if the model is easy to change by a consultant, or even by the decision makers themselves, so they can quickly respond on the developments and see how this impacts their decision.

8.6 Chapter Summary

This chapter presented the results of the evaluation of the decision aiding approach. The decision aiding approach did support the decision makers to select a Pareto optimal solution, and an increase in awareness can be seen. A strength of the decision aiding approach is the strong involvement of decision makers from different perspectives, especially in the problem formulation phase. A weakness of the approach is that it does not include an implementation phase. In addition, several improvement possibilities are suggested for the visualisation, such as adjusting the selection brush labels and adding a feature to compare different solutions. The next chapters will use this information to answer the research question and conclude this research.

9 | Discussion

In this chapter presents a reflection on the designed decision aiding approach and its strengths and weaknesses. This reflection forms, together with the results described in the previous chapters, the basis for the conclusions of this research.

9.1 Reflecting on the Decision Aiding Approach

Often, decision aiding is focused on the construction of the evaluation model, the formal model which is constructed by the analyst which aims to evaluate potential solutions and provides information about the problem (Tsoukiàs, 2007). Frequently, it is assumed there is an existing problem formulation and this problem formulation is used to create the evaluation model. Many papers discussing the use of simulation optimisation or MOO do not, or only very briefly, discuss how the problem formulation was established, as for example can be seen in Kasprzyk et al. (2013); Kollat et al. (2011); Labadie (2004). Other approaches to decision aiding focus merely on problem structuring and formulation, supposing that formulating a problem is equivalent to solving the problem (Tsoukiàs, 2007). Some authors claim that decision aiding is equal to problem formulation (Checkland, 1981; Rosenhead, 1989). The constructive decision aiding approach as designed in this research equally values both aspects of decision aiding. It is believed that an evaluation model does not truly represent the problem when the problem formulation is seen as given beforehand. It is, however, also believed that the decision aiding does not stop after the problem formulation. Using an evaluation model, such as a simulation optimisation model, provides the opportunity for the decision makers to gain quantitative information about potential solutions, which allows them to substantiate their preferences and decision with numbers instead of experience and feeling. It is believed that especially with a method such as simulation optimisation, the decision makers need to be supported by an analyst with methodological knowledge about simulation, optimisation and visualisation who can help them to interpret the results.

The decision aiding approach can be of value in a decision making process, in essence that it provides the decision makers with a set of Pareto optimal solutions and knowledge about dependencies and trade-offs between objectives. This is seen as substantive value, since it mainly contributes to the content of the decision making process. In addition to the substantive value the decision aiding approach can have, it is seen that the approach has strategic value as well. Strategic value is considered to be value for the process of the decision making, for example concerning the relationship between the decision makers. Bringing decision makers together and actively trying to come to a shared problem overview and decision, results in an increased understanding of each others values and preferences. The use of Many-Objective Optimisation, allowing for the incorporation of multiple, conflicting objectives, provides the opportunity for the stakeholders to see how their decisions influence the objectives of others. This, in combination with the fact that they can discover these dependencies themselves using the interactive visualisation, created a strong impact on the decision makers. This was especially seen in case study I, where there was no solution present which could fulfil the constraints of all decision makers. This led to an increase in the negotiation margin of the decision makers. It could be stated that the information from the SO model increased the willingness of the decision makers to stretch their constraints. This can lead to a faster decision making process. Where the ability of MOO to generate substantial insight on trade-offs and dependencies between objectives can be frequently found in literature, see for example (Deb, 2010), this strategic function of a decision aiding approach with (Simulation-Based) Many-Objective Optimisation is scarcely addressed.

The following subsections reflect on the three design artefacts and the integration of the artefacts.

9.1.1 Reflecting on the Decision Aiding Process

It is observed that inviting different stakeholders from the beginning, and bringing them together in selecting a solution, is very valuable for the support a solution receives (De Bruijn, 2008). Since the decision makers all contributed to constructing the problem formulation and thus multiple perspectives are taken into account, it is believed that the formulated problem is a better representation of the real problem. In this way, the decision makers can all recognise their own ideas and experiences in the formulation, compared to a situation in which the problem formulation was created only from one perspective.

The decision aiding process is time intensive for the analyst and incorporates many iterations, especially compared to a situation in which the problem was approached as well-structured. This is in line with literature about semi-structured and ill-structured problem formulation, such as (De Bruijn, 2008; Tsoukiàs, 2008; Checkland, 1981). This is not seen as a negative point, but is however, important to take into account while executing such a decision aiding approach, especially when the analyst is used to working with a given problem formulation. The iterations take place from the beginning till the negotiation session, and sometimes even during the session. Often, if a decision maker changes his/her perspective on a certain objective, or if new information is revealed, the problem formulation changes and thereby the evaluation model must be adjusted. Where iterations should be stimulated on the one hand, since it promotes a proper representation of the problem, it is sometimes complicated to incorporate such changes in the model. In addition, it is believed that in a business context, most decision makers aim to work effective and efficient, and having a very iterative process can cause frustration (Keen and Morton, 1978). It takes time to come to a proper problem formulation and evaluation model, and this should be clearly stated in the beginning of the project to all involved parties. But, when the analyst notices that no new information is provided by the decision makers about the problem overview, this can be seen as a right moment to continue to the next step of the decision aiding process, to ensure the process does not becomes sluggish (De Bruijn, 2008).

Where many of the decision support and decision aiding methods state or assume that it is the task of the analyst to present an advice to the decision makers, the designed decision aiding approach does not do this. Tsoukiàs (2007) nuances this, stating that the final recommendation is formulated by the analyst and decision maker(s) together. It is part of the designed decision aiding process that the analyst explains the results to the decision makers, but they can themselves, where needed with help of the analyst, explore the results and come to a decision. Within the decision process, there does not exists such a thing as a final recommendation or advice formulated by the analyst to the decision makers. This can be seen as a strength, since it enables the decision makers to completely control and own their own decision. However, it can also be seen as a weakness, when the decision makers are not able to deal with the complex results of the SO model and get lost in information. In that case, it might be useful when an analyst presents an advice to guide them in the right direction. Therefore, it is important that the analyst, during the negotiation session carefully monitors the understanding of the decision makers about the results, and intervenes when he/she believes the decision makers need help interpreting the results.

9.1.2 Reflecting on the SO Model

Even though Many-Objective Optimisation can also be used without simulation, this research specifically focused on Simulation-Based Many-Objective Optimisation. The use of simulation is not only a method for solution evaluation underlying the optimisation, the simulation model can function as a communication tool as well. Using a complex analytical tool in a decision aiding approach often leads to the risk of the tool being a black box, impacting the trust of the decision makers in the results (Branke et al., 2008; De Bruijn, 2008). Making use of simulation, validating the simulation model together with the decision makers is possible due to the animation function which is often available in simulation software. This enables the decision makers to see the working of the model, recognise their situation in the model, and to improve the model. Simulation can thus be used as a tool to come to a better problem formulation and to increase the trust of the decision makers in the results. In addition, the simulation model can be used as well to increase the understanding about optima arising from the optimisation, by showing the decision maker how the system is expected to perform given certain input variables. It is thus seen as valuable to use MOO in combination with simulation, not only to be able to run the optimisation, but also to involve the decision makers and communicate solutions.

In the two cases the creation of the DES model was accelerated by the availability of data. Even though the data was not always available in the right units to construct the model in one go, and even though the validity of the data was sometimes contested by the decision makers, it provided a foundation for the creation of the DES model. Without any data, creating this model would have been hard and many assumptions would have been necessary.

Running the optimisation takes time. Even though the run time of the model was not long, for example in the first case about 30 seconds, running 5000 iterations of the optimisation algorithm with sufficient replications of the model already would have taken three to four days. This problem partially was solved by running several iterations in parallel. The ϵ-NSGA-II algorithm allowed for this possibility, and this was one of the main reasons why this algorithm was preferred to the BORG-algorithm. This significantly reduced the run time to about one day. Still, the optimisation requires a large amount of computational power, making it less flexible to frequent adjustments in the problem formulation, as can be asked for during the negotiation session.

In Case II it was experienced that the SO model resulted in over 5000 possible solutions. Even though this is in line with literature, for example Jaszkiewicz and Branke (2008, 183) state that *"even for relatively small problems [the solutions set] may contain thousands of solutions"*, it was decided that this was too much to confront the decision makers with, since this could not be visualised properly in the designed visualisation. Therefore, the analyst made a pre-selection. Many of the solutions scored badly on one particular objective: the inventory at the beginning of peak week. Since the aim is to have zero inventory at the beginning of peak week, all solutions which had more than 1000 hours of inventory were deleted. In the end a solution set of 500 remained, which was presented to the decision makers. It is, however, not completely clear why the model resulted in so many solutions and how to deal with this amount of solutions in the visualisation.

A final point of attention is the possibility to iterate on the problem formulation of the optimisation model. It was noticed that during the negotiation sessions new questions popped up, such as: "but what if we had not taken the average of objective X, but how many days it is below Y?". In the time frame of one hour, there was only time to discuss one problem formulation. New problem formulations will result in a new solution set, and it might be the case that in that solution set a solution exists which fulfils all preferences where this was not the case in the current set, or comes closer to this (Kasprzyk et al., 2015). This possibility could have been especially valuable in case I, where the used problem formulation resulted in no possible solutions which fulfilled all constraints. It was not possible to run a new problem formulation in the time span of the negotiation session, which could then immediately be discussed, due to constraints in computational power. Another option would be to organise a second round where new problem formulations could be discussed. Due to time constraints this opportunity was however not explored.

9.1.3 Reflecting on the Visualisation

The evaluation interviews revealed that the decision makers truly valued the interactiveness of the graph, which allowed them to explore the results of the SO model. This was in contrast with what the decision makers normally experienced, where mostly only the advice or a single result of the model was presented to the involved stakeholders. The decision makers stated that exploring the results and experiencing the dependencies between objectives and thus between the stakeholders themselves was more valuable compared to being presented with a single advice. The value of the visualisation can be found both in substance, communicating the results of the SO model and in this way increasing the awareness of decision makers (Munzner, 2014), and strategic, increasing the support for and ownership of the solution.

It was interesting to notice how the decision makers dealt with the visualisation, especially since none of them had worked with such an interactive graph before. It is desired that a visualisation is self-explanatory (Tufte, 1983). Nevertheless, the designed visualisation requires an explanation to ensure a basic level of understanding of the graph. It can be stated that the users must learn how to read the graph. This is, however, not seen as a large drawback, since in both case studies the decision makers were able to properly use the graph after a short explanation and a short practise period. It is estimated that this requires about 15 minutes in total. It might be useful to let the decision makers 'practise' with a dummy visualisation to ensure everybody understands the working of the graph. During the cases this was done by letting them individually explore the results, but doing this with a comparable dummy graph could have worked as well. The graph worked intuitively and did not seem to be too complex for the decision makers, even decision makers with no experience with such extensive interactive visualisations.

It is observed that the graph can be improved in several ways which are all described in Section 8.4. It is believed that especially the possibility to indicate solutions within a certain bandwidth close to the preferences of the decision makers could make the negotiation session more effective. Furthermore, improving the selection brush labels might save confusion of the decision makers.

9.1.4 Reflecting on the Design Integration

It is experienced that the 'soft' decision aiding process and the 'hard' simulation optimisation model can complement each other. Where the decision aiding process stimulates the creation of a shared problem overview, the SO model brings quantitative data to support the negotiation. The fact that the decision makers can underpin their ideas with analytic insights was very valuable to them. The visualisation works well as a tool to communicate the results of the model, and allows for a real-time support of the discussions with facts. Even though it might sometimes be challenging to translate the problem overview of the decision makers in a quantitative problem formulation, for example because not everything can be quantified or modelled in the system, it is felt that incorporating more than one perspective in the problem formulation improves the quality of the solution and the support of the different stakeholders for the solution.

Some remarks on the integration can be made. First, it would be hard to translate the problem overview of the decision makers to a simulation model when there is little data available. Creating a simulation model is a data intensive method, and without some basic data the complete model has to be based on assumptions (Banks, 1999). This can question the validity of the model and the extent to which the results are seen as a strong indication of what will happen. Second, it is important for the analyst to take into account that the time the decision makers need to understand the working of the visualisation during the negotiation session varies. This brings the risk that decision makers which understand the graph more quickly have a larger impact on the final decision. A comparable graph which can be used to practise could be valuable in mitigating this risk.

9.2 In Addition: Some Remarks on the Role of the Analyst in the Decision Aiding Approach

It should be stated that even though the analyst follows the decision aiding approach exactly as stated in this research, much depends on the complexity of the problem, the time which the decision makers have available and the expertise of the analyst on problem solving, quantitative modelling and the problem domain. The more complex the problem is, the more iterations probably are necessary. If the decision makers are not willing to spend time on the project, it should be questioned by the analyst whether a proper problem formulation can be established and if there is enough urgency to continue with the approach. The quality of the results from the MOO model depends for example on the ability of the analyst to translate the overview in the simulation model, and the performance of the MOEA. Furthermore, the interaction between the analyst and the decision makers, and between the analyst and the three elements of the decision aiding approach can influence the outcomes of the decision aiding approach. This indicates that even if the decision aiding process is followed exactly as stated, this does not guarantee a good outcome of the decision aiding approach.

9.3 Elucidating on Strengths & Weaknesses

Based on the evaluation of the decision aiding approach, different strengths and weaknesses are identified, of which Table 9.1 presents an overview. To ensure a comprehensive overview, the strengths and weaknesses are divided in a substance, strategic and technical category. The category 'substance' includes items related to the content of the decision aiding approach, such as the mathematical quality of the solution. The category 'strategic' includes items that are related to the decision making process and its decision makers. The category 'technical' are for example concerned with the working of the SO model.

	Strengths	**Weaknesses**
Substance	• Only Pareto optimal solutions in the solution set • Increase in awareness of decision makers • Analytical substantiated decision instead of a decision based on 'feeling'	• Data intensive method • Only quantitative objectives can be incorporated in the model • Model and results cannot easily and / or quickly be adjusted to changes in the business process
Strategic	• Using a simulation model with animation function increases the confidence the decision makers have in the results • It can increase negotiation margin of decision makers, leading to a faster convergence towards a solution • Increases the support for the selected solution • Interactive result exploration increases involvement of the different decision makers and ownership of the solution	• Time intensive for both analyst and decision makers • Approach does not include an implementation phase
Technical	• Using a simulation model with animation function makes it possible to animate the chosen solution • Different MOEAs can be connected to the simulation model	• Long run time makes it impossible to experiment with different problem formulations during the negotiation session • The lines in the visualisation are not visible anymore when over a thousand data points are plotted (solutions)

Table 9.1: Strengths & weaknesses of the decision aiding approach

9.4 Generalizability of the Decision Aiding Approach

The decision aiding approach is designed keeping in mind that it is applied to a semi-structured problem in the operational core of a large organisation (Mintzberg, 1993). It can be questioned whether the approach can be applied in other situations as well, for example to well-structured problems, or problems with high level strategic decision makers. Three remarks on the generalizability can be made.

First, it is believed that the designed decision aiding approach could be valuable for ill-structured problems as well. However, the dynamics in the decision aiding approach can be different. Due to the less-structured nature of the problem, coming to a shared problem overview and a formal problem formulation might be more difficult. Knowledge and data can be more contested, and stakeholders will probably have more conflicting perspectives, making it more difficult to agree upon assumptions and modelling choices (De Bruijn et al., 2010). Often, ill-structured problems have a more strategic and long term focus than semi-structured problems. The decision makers probably do not all work within the same company, making it more difficult to find a shared goal. This can result in more strategic behaviour, such as blocking decision making, or withholding information. This can lead to a more sluggish decision making. Nevertheless, it is believed that, taking into account these different dynamics, the use of a decision aiding approach can be valuable in such a situation. Especially the eye-opening fact that there might be no solution possible which satisfies all decision makers, might increase the willingness to negotiate about constraints.

Second, applying this decision aiding approach to a well-structured problem could be valuable, but it is believed that when a problem truly is well-structured such an extensive problem formulation phase might not be necessary. Nevertheless, increasing awareness in for example the trade-offs between the objectives can still be valuable. The decision aiding approach can be used with a strong emphasis on the model creation and results exploration phase, instead of focusing time and resources to the problem formulation. It should however be questioned whether there are other methods available which also increase the awareness of the decision makers, but are less time or computational intensive.

Third, the decision aiding approach focused mainly in business process improvement problems. This can be seen as a type of process design problem. It can be wondered whether the approach works for new process design problems as well, for example when it is uncertain during the design of a new process how particular process variables should be tuned to generate a good performance. It is believed that these problems share much of the characteristics of a process improvement project, and thus the decision aiding approach can be valuable. It should however be taken into account that when improving an existing process much data is available, while for researching a to be implemented process less data probably is available. This can complicate the creation of the simulation model.

9.5 Chapter Summary

This chapter presents a discussion on the designed decision aiding approach. In the reflection several findings are compared to findings from scientific research, and experiences from applying the approach are shared. An overview of strengths and weaknesses is given, based on the results from Chapter 8. Last, the generalizability of the approach to other type of problems is discussed.

10 | Conclusion

This chapter concludes this thesis by presenting the answer to the main research question as posed in Chapter 1. After answering this question, the scientific and practical contributions are discussed. Thereafter the limitations of this research are discussed. This chapter ends with suggesting possibilities for future research.

10.1 Main Findings

The main research question of this research is formulated as follows:

What is the added value of a decision aiding approach with Simulation-Based Many-Objective Optimisation for a semi-structured process improvement problem?

To answer this question a constructive decision aiding approach is designed, which is applied to two cases and evaluated afterwards. The design consists of three parts, which together form a coherent decision aiding approach. This approach is discussed in Chapter 4. The first part of the design is a constructive decision aiding process. This process is seen as a stepwise guidance for the analyst executing the decision aiding approach. The second part of the design in the simulation optimisation model, in which the problem is simulated and optimised. The third part of the design is an interactive graph, used to visualise the results of the model. The visualisation is crucial to give meaning to the results and to deal with the risk of an information overload.

The three design artefacts are integrated in the decision aiding approach. The three artefacts depend on each other to work properly and strengthen each other. To be able to conclude upon the added value, the approach is applied in two cases at ING Bank. The added value is split in two types; substantive value and strategic value. Substantive value relates to value regarding the content of the improvement problem, for example the quality of the solution. Strategic value relates to value for the decision making process, such as more support for the selected solution.

Only Pareto Optimal Solutions are Present in the Solution Set (Substantive)

In comparison with frequently used process improvement methods, an advantage of Simulation-Based Many-Objective Optimisation is that it only results in Pareto optimal solutions. When using other methods, such as Lean Six Sigma or a classical simulation study, it is unknown whether the solution is Pareto optimal or not. Mathematically seen, selecting a solution which is not Pareto optimal is a waste of potential value. Presenting only Pareto optimal solutions increases the chance that an optimal solution is chosen.

Increase in Awareness of Decision Makers (Substantive & Strategic)
The decision aiding approach did result in an increase in the (self-rated) awareness of the decision makers. The strongest increase was seen in both case studies in the awareness about the trade-offs between the objectives. This increase resulted mainly from the way the results were visualised; showing the dependencies between objectives and letting the decision makers 'play' with the results is very valuable. This is seen as substantive value.

In addition, also an increase in awareness about the preferences of other decision makers was seen. This increase can mainly be explained by the fact that during the decision aiding approach the different decision makers had a lot of discussions about the problem, the objectives and their preferences. These discussions contributed to the awareness of the preferences of others. The increase in awareness is expected to contribute to more efficient decision making, since the decision makers can anticipate on the preferences of others. This is believed to be of strategic value for the decision making process.

Faster Convergence Towards a Solution (Strategic)
The use of Simulation-Based Many-Objective Optimisation can lead to faster convergence of the preferences of the decision makers and thus more progress in the decision making process. The decision makers rated on a five-point scale how much 'room for manoeuvre' they were willing to use. Especially in the case I an increase is seen after the decision makers individually explored the results. The motivation for the increase turned out to be the awareness of the decision makers that there did not exist a solution that was perfect for all decision makers, and thus trade-offs had to be made. Noticing this resulted in a change in attitude of the decision makers and made them more willing to do concessions to come to an acceptable solution for all decision makers. Thus, the use of Simulation-Based Many-Objective Optimisation can make the decision makers more flexible in the negotiation, which can increase convergence and lead to faster decision making.

More Support and Ownership for the Selected Solution (Strategic)
By approaching the problem not from a single perspective but from multiple perspectives and by involving the different stakeholders in the decision aiding approach, the solution gained support from all different stakeholders. In comparison with a method such as Lean Six Sigma, where a business process is improved from only one perspective, the decision aiding approach is expected to lead to more support since everybody did agree on the selected solution and it is not imposed

on the employees. It is expected that this support will smooth the implementation of the solution, which is valuable to gain the benefits of the solution as fast as possible.

In addition, the fact that the decision makers could select the solution themselves using the interactive graph, instead of a single solution being advised by the analyst, increased the ownership the decision makers felt for the selected solution. This again can smooth the implementation, since the decision makers are less dependent on the analyst and see it as their own project.

Trust of the Decision Makers in the Results (Strategic)
Especially the validation session of the simulation model contributed to the understanding of the decision makers about the working of the model and the obtainment of the results. In the evaluation interviews several of the decision makers declared that this validation session ensured them that the simulation model was aligned with the real problem, and that this increased their trust in the results. Even though the optimisation itself still is perceived as a black box by the decision makers, this was not an important issue for them because they understood the working of the model. This indicates that, in comparison to using MOO without a simulation model, the combined method can lead to more trust in the results.

In addition, the simulation model can also be used as a communication tool to animate the selected solution. In this way, the understanding of the working and the effect of the selected solution can be improved.

10.2 Concluding upon Scientific Contribution

The combination of decision aiding and Many-Objective Optimisation is mentioned in literature, but mostly implicitly or shallowly. In this research addressed a decision aiding approach which combines constructive decision making with MOO explicitly to allow for reproduction, reuse and improvement. The decision aiding approach can function as a stepwise guide for analysts aiming to apply Simulation-Based Many Objective Optimisation. The decision aiding approach combines the soft systems paradigm and the hard systems paradigm by combining constructive decision aiding with Simulation-Based Many-Objective Optimisation. It is believed that the two approaches complement each other in the decision aiding approach; the constructive decision aiding leads to a better formal problem formulation, and the Simulation-Based Many-Objective Optimisation leads to more substance in the decision making process.

This research shows that the decision aiding approach can have both substantive and strategic value. Where multiple substantive benefits are addressed in literature, such as the ability to provide insight in the dependencies and trade-offs between objectives, the strategic role of Simulation-Based MOO in a decision making process is not frequently addressed. This research concludes that, when applying the approach to a semi-structured process improvement project, the approach can lead to faster convergence of the preferences of the decision makers, more support for the selected solution from all involved stakeholders and an increased ownership of the solution by the decision makers.

10.3 Concluding upon Practical Contribution

The decision aiding approach can function as a stepwise guide for the analysts of ING, or analyst within other companies, when tackling a semi-structured process improvement problem. It was noticed that the decision aiding approach matched well with the self-steering organisation of ING, since this allows the decision makers to be self-steering, instead of the analyst advising them what to do, but enables them to make the decision based on a substantiated analysis instead of based on 'feeling and experience'. The approach allows for the involvement of multiple different stakeholders in the decision making process, instead of the analyst formulating an advice. This again fits well with the self-steering strategy of ING.

The decision aiding approach was valuable for the decision makers to gain knowledge about the trade-offs, to be able to formulate fact-based performance objectives and to gain knowledge about how to design their process to reach the performance objectives. It can be valuable especially in problems where there are multiple conflicting objectives and where it is unclear how all performance objectives can be reached.

It is seen that approaching a process improvement problem as semi-structured instead of well-structured can be valuable. It can lead to an increase in support and ownership for the selected solution, and to a solution which better solves the problem. Approaching the problem as semi-structured does make it, however, less straightforward to solve. There will not be one straightforward optimal solution, and the analyst loses the control over the selection of the solution. This should be taken into account by the analyst.

10.4 Research Limitations

This research uses the theory of Endsley (1995) which states that if the awareness of decision makers about business process improvement possibilities is increased, the decision makers select a better solution than if they were less aware. However, this can be questioned. In this research, it was not possible to compare the decision making process with the designed decision aiding approach to a similar decision making process without the approach or with another comparable method. This comparison was not possible, since it was not possible to have two projects running parallel due to the time investment this would ask from the stakeholders at the departments. In addition, many of the decision makers which were involved were part of the middle-management, and in this way it was hard to compose two comparable groups of decision makers. When this would have been possible, a randomised control trial could be set up. Since this is not done in this research, no objective comparison can be made. The decision makers can however clearly compare their experiences to experiences from previous projects where other methods were used, such as Lean Six Sigma. By asking the decision makers about the differences, a clear view could be composed about the differences and the value of the designed approach. It is believed that by applying the approach in two case studies, insight can be gathered about the possible effect on similar cases, even though the number of observations is low and no objective comparison is made. However, generalising these insights to other cases must be done with care.

In addition, since the implementation of the solution was beyond the scope of this research, the performance of the process with the selected solution cannot be compared to the performance before the decision aiding approach. Another complicating factor to determine the delta in performance is that the performance is currently not measured for all objectives. This makes it hard to compare both situations. In the end, it cannot yet be claimed that the decision aiding approach improved the business process.

Another limitation of the research is that due to time constraints there was no possibility to use multiple different problem formulations for the optimisation. As stated in Section 1.1.1, the problem formulation influences the outcomes of the model. Using multiple problem formulations could results in more diverse solutions and a higher chance that there is a solution which is acceptable for all decision makers. It was also noticed that during one of the negotiation sessions, new questions popped up which would have asked for a different problem formulation. Ideally, it would be possible to formulate this new problem formulation during the session, run the algorithm and present the new results in a later session, on even better, in the same session. This last aspect would require the algorithm to have a very short run time, which was not the case in the two cases. In conclusion, it would have been valuable if there was time for more iterations on the problem formulations and potentially multiple negotiation sessions about the results.

A limitation in the setup of the evaluation of the decision aiding approach can be found in the method of evaluating the increase in situation awareness. Since it was not clear in the beginning which stakeholders would be involved during the process, and which solutions and objectives were included in the problem formulation, it was chosen to measure the awareness of the decision makers not at the very beginning of the approach, but after the problem structuring. This is, however, not a true baseline measurement. The first steps of the decision aiding approach could already have influenced the situation awareness of the decision makers. Nevertheless, since the decision makers rate their awareness multiple times, still an increase in awareness can be seen between the first measurement after the problem formulation, and after the negotiation session. This self-rating technique can provide us with an indication of an increase, but cannot present an absolute and objective increase in situation awareness.

An additional risk of how the awareness is measured is the risk on framing the decision makers by letting them individually 'play' with the results during the negotiation session. Even though this contributed to the understanding of the decision makers about the working of the visualisation, and contributed to the awareness of the decision makers about business process improvement possibilities, this probably results in a different negotiation between the decision makers compared to a situation in which they immediately start the negotiation collectively. In this research, this decision was made to isolate the effect of exploring the insights individually, and discussing the results collectively on the situation awareness. Furthermore it could stimulate an efficient negotiation since the decision makers already gained some knowledge about the possible solutions and the trade-offs between objectives. A potential drawback is that the decision makers which understood the visualisation quickly already were more aware of the possibilities than decision makers which needed more time to understand the visualisation. This could result in an uneven start position in the negotiation. This is however not experienced during the case studies.

A final limitation of this research is that the performance of the MOEA is not measured. The performance of the MOEA influences the quality of the results and is therefore important to take into account. This was however beyond the scope of this research, but would be advised to check when using the decision aiding approach.

10.5 Improvement Possibilities & Future Research

Several suggestions for future research can be done, based on the improvement possibilities and the limitations of this research. It would be interesting to execute the decision aiding approach while running another decision aiding project using a classical simulation study, or other method which is normally used by the decision makers, and compare the results of both groups. In this way it can be researched whether the decision aiding approach results in a better performance of the business process.

Furthermore, it would be valuable to extend the decision aiding approach with an implementation phase. Future research can result in insights how this implementation can be best incorporated in the decision aiding approach. Moreover, such a research project can address whether the expected performance is realised when the selected solution is implemented.

This research did not have enough time to incorporate the use of different problem formulations in the decision aiding approach. It would be interesting, especially in cases where there is no solution which satisfies the constraints of all decision makers, to incorporate the possibility to use multiple different problems formulations to see how this affects the decision aiding.

Another aspect of the decision aiding approach which can be improved with future research is the visualisation. This research can focus on whether the labels accompanying the brushes are more clear when they show the value on the axes which is selected instead of the value of the most upper or lower data points. Furthermore, it can be researched whether the possibility to show solutions within a certain bandwidth of the preferences can help the decision makers in their negotiation.

Last but not least, it would be interesting to apply the designed decision aiding approach to different types of organisations in comparable domains, and/or to comparable type of organisations in different domains. This research used two cases related to a customer contact process of a large bank. However, many organisations, in for example the telecommunication or health care domain, deal with comparable problems. It would be interesting to apply the decision aiding approach in other organisations to be able to draw conclusions about the applicability of the decision aiding approach to different types of organisations and/or domains. Furthermore, future research could be done to applying the decision aiding approach to ill-structured problems, to see what the added value of the approach is for such a problem.

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A | Questionnaire to Evaluate Situation Awareness

This appendix contains the questionnaire which is used to measure the situation awareness of the decision makers. In total seven decision makers filled in the questionnaire; four from case I and three from case II. The questionnaire is in Dutch.

Enquête 1

Naam: ....

Deze enquête dient ter voorbereiding op de resultatensessie van [datum]. Heel fijn dat je hem invult! Het invullen zal ongeveer 10 minuten duren. In de volgende vragen wordt er gevraagd naar jouw voorkeuren op bepaalde punten. Je kunt hier in een range aangeven, of één getal. Bijvoorbeeld:

Vraag: Wat is jouw voorkeur qua reistijd naar je werk?

Antwoord: 5 minuten.
Of
Antwoord: tussen de 0 30 minuten.
Of:
Antwoord: geen mening

Het is de bedoeling dat je of een range aangeeft, of één getal; dus niet allebei. Indien je geen mening hebt op een bepaalde variabele, kun je geen mening aanvinken.

1. Wat zijn jouw voorkeurs waardes/ranges op de volgende punten?

a. Doel 1:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

b. Doel 2:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

c. Doel 3:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

d. Doel 4:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

e. Doel 5:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

f. Doel 6:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

2. Wat zijn jouw voorkeurs waardes/ranges op de volgende oplossingen?

a. Oplossingsvariabele 1:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

b. Oplossingsvariabele 2:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

c. Oplossingsvariabele 3:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: geen mening*

Bedankt voor het invullen van je voorkeuren. Nu volgen er een aantal stellingen waarin je kunt aangeven in hoeverre je het hier mee eens bent.

3. Hoeveel ruimte is er voor onderhandeling op de voorkeuren die je zojuist hebt aangegeven?

Zeer weinig ruimte 1 2 3 4 5 Zeer veel ruimte

4. Hoe zeker ben je van je voorkeuren?
Zeer onzeker 1 2 3 4 5 Zeer zeker

5. Ik zie in met welke knoppen we de doelen kunnen beinvloeden.
Zeer oneens 1 2 3 4 5 Zeer eens

6. Ik zie in hoe deze knoppen de doelen beinvloeden.
Zeer oneens 1 2 3 4 5 Zeer eens

7. Ik zie in hoe de verschillende doelen elkaar beinvloedden.
Zeer oneens 1 2 3 4 5 Zeer eens

8. Ik zie in wat de voorkeuren op bovenstaande doelen en knoppen zijn voor personen die vanuit een ander perspectief redeneren.
Zeer oneens 1 2 3 4 5 Zeer eens

9. Overige opmerkingen:

a. N.v.t.

b. ....

Enquête 2

Naam: ....

1. Na het zien van de resultaten, wat zijn nu jouw voorkeuren? Vul de waardes in die je in de grafiek geselecteerd hebt. Indien je niets hebt geselecteerd, dan kun je n.v.t. invullen.

a. Doel 1:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

b. Doel 2:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

c. Doel 3:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

d. Doel 4:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

e. Doel 5:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

f. Doel 6:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

a. Oplossingsvariabele 1:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

b. Oplossingsvariabele 2:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

c. Oplossingsvariabele 3:
Antwoord: ... [unit] *Antwoord: tussen ... - ... [unit]* *Antwoord: n.v.t.*

2. Hoeveel ruimte is er voor onderhandeling op de voorkeuren die je zojuist hebt aangegeven?

Zeer weinig ruimte 1 2 3 4 5 Zeer veel ruimte

3. Hoe zeker ben je van je voorkeuren?
Zeer onzeker 1 2 3 4 5 Zeer zeker

4. Is dit een verandering ten opzichte van de voorkeuren die je voorafgaand aan deze meeting in de enquête had aangegeven?
A. Ja *(beantwoord vraag 5 tot en met 9)* B. Nee *(beantwoord vraag 10 tot en met 14)*

Vraag 5 tot en met 9 hoef je alleen te beantwoorden als je op vraag 4 **JA** hebt geantwoord.

Hieronder volgen vier stellingen. Indien je je niet herkent in de stelling, dan vul je (zeer) oneens in. Indien je je wel herkent in de stelling, dan vul je (zeer) eens in. Bijvoorbeeld:

Ik heb mijn waardes veranderd omdat ik inzie met welke knoppen we de verschillende doelen kunnen beinvloedden.

Indien je je mening niet hebt veranderd omdat je inziet met welke knoppen je de verschillende doelen kunt beinvloedden, dan vul je (zeer) oneens in. Indien je je mening wel hebt veranderd omdat je inziet met welke knoppen je de verschillende doelen kunt beinvloedden, dan vul je (zeer) eens in.

5. Ik heb mijn waardes veranderd omdat ik inzie met welke knoppen we de verschillende doelen kunnen beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

6. Ik heb mijn waardes veranderd omdat ik inzie hoe deze knoppen de verschillende doelen beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

7. Ik heb mijn waardes veranderd omdat ik inzie hoe de verschillende doelen elkaar beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

8. Ik heb mijn waardes veranderd omdat ik inzie wat de ideale waardes op bovenstaande doelen en knoppen zijn voor betrokkenen die vanuit een ander perspectief redeneren.

Zeer oneens 1 2 3 4 5 Zeer eens

9. Overige redenen waarom ik mijn waardes veranderd heb veranderd:

a. N.v.t.

b. ....

....

Vraag 10 tot en met 14 hoef je alleen te beantwoorden als je op vraag 4 **NEE** hebt geantwoord.

Hieronder volgen vier stellingen. Indien je je niet herkent in de stelling, dan vul je (zeer) oneens in. Indien je je wel herkent in de stelling, dan vul je (zeer) eens in. Bijvoorbeeld:

Ik zie in met welke knoppen we de verschillende doelen kunnen beinvloedden.

Indien je hier niet of weinig inzicht op hebt, dan vul je (zeer) oneens in. Indien je hier wel inzicht op hebt, dan vul je (zeer) eens in.

10. Ik zie in met welke knoppen we de verschillende doelen kunnen beinvloedden.
Zeer oneens 1 2 3 4 5 Zeer eens

11. Ik zie in hoe deze knoppen de verschillende doelen beinvloedden.
Zeer oneens 1 2 3 4 5 Zeer eens

12. Ik zie in hoe de verschillende doelen elkaar beinvloedden.
Zeer oneens 1 2 3 4 5 Zeer eens

13. Ik zie in wat de ideale waardes op bovenstaande doelen en knoppen zijn voor personen die vanuit een ander perspectief redeneren.
Zeer oneens 1 2 3 4 5 Zeer eens

14. Overige opmerkingen:

a. N.v.t.

b. ....

....

Enquête 3

Naam: ....

1. Hoe zeker ben je van de gekozen oplozzing?

Zeer onzeker 1 2 3 4 5 Zeer zeker

2. Is dit een verandering ten opzichte van de waardes die je zojuist individueel als voorkeur had aangegeven?

A. Ja *(beantwoord vraag 3 tot en met 7)* B. Nee *(beantwoord vraag 8 tot en met 12)*

> Vraag 3 tot en met 7 hoef je alleen te beantwoorden als je op vraag 3 **JA** hebt geantwoord.
>
> Hieronder volgen vier stellingen. Indien je je niet herkent in de stelling, dan vul je (zeer) oneens in. Indien je je wel herkent in de stelling, dan vul je (zeer) eens in.

3. Ik heb mijn waardes veranderd omdat ik inzie met welke knoppen we de verschillende doelen kunnen beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

4. Ik heb mijn waardes veranderd omdat ik inzie hoe deze knoppen de verschillende doelen beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

5. Ik heb mijn waardes veranderd omdat ik inzie hoe de verschillende doelen elkaar beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

6. Ik heb mijn waardes veranderd omdat ik inzie wat de ideale waardes op bovenstaande doelen en knoppen zijn voor betrokkenen die vanuit een ander perspectief redeneren.

Zeer oneens 1 2 3 4 5 Zeer eens

7. Overige redenen waarom ik mijn waardes veranderd heb veranderd:

a. N.v.t.

b. ....

....

> Vraag 8 tot en met 12 hoef je alleen te beantwoorden als je op vraag 3 **NEE** hebt geantwoord.
>
> Hieronder volgen vier stellingen. Indien je je niet herkent in de stelling, dan vul je (zeer) oneens in. Indien je je wel herkent in de stelling, dan vul je (zeer) eens in.

8. Ik zie in met welke knoppen we de verschillende doelen kunnen beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

9. Ik zie in hoe deze knoppen de verschillende doelen beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

10. Ik zie in hoe de verschillende doelen elkaar beinvloedden.

Zeer oneens 1 2 3 4 5 Zeer eens

11. Ik zie in wat de ideale waardes op bovenstaande doelen en knoppen zijn voor personen die vanuit een ander perspectief redeneren.

Zeer oneens 1 2 3 4 5 Zeer eens

12. Overige opmerkingen:

a. N.v.t.

b. ....

....

B | Outline Semi-Structured Evaluation Interviews

To achieve insights in the value of the decision aiding approach, and to be able to identify the strengths and weaknesses, interviews are used. This appendix presents the protocol used during interviews. The results of the interviews can be found in Appendix G. Eleven interviews were conducted with employees of ING. Four different type of employees are interviewed:

1. Decision makers who were involved in the case studies (7 persons)
2. Operational excellence consultant who was involved at one of the case studies (1 person)
3. Operational excellence consultants who were not involved during the case studies, but are familiar with the use of simulation models (2 persons)
4. Manager of the operational excellence department (1 person)

The interviews are semi-structured. In this way it can be ensured that all necessary information is gathered, and there is enough space for the interviewee to give additional information. Since the interviewees all have a different role and expertise, not every interview is structured in the same way and not all topics are relevant for all interviewees. The structure presented below provides an overview of all topics and related questions. Per interview the topics which are relevant for the interviewee are selected. The interviews are processed anonymous in this research, only the role of the interviewee is stated.

Note: Since all interviews were held in Dutch, the outline of the interviews is also written in Dutch.

Interviewer	Stephanie van den Boogaard
Interviewee	....
Role	....
Date	....

1. Introduction

Welkom, goed dat je er bent. In dit interview zullen we het gaan hebben over het proces dat we met elkaar hebben doorlopen en wat de impact hiervan is geweest. Dit gebruik ik in mijn onderzoek om verbeterpunten te identificeren en om de impact the evalueren. Het interview zal ongeveer een half uur duren en de resultaten zullen anoniem worden verwerkt. Ik wil hierbij graag vermelden dat voor mij iets dat je niet goed vond gaan erg waardevol is voor mij, zodat ik verbeterpunten kan aangeven. Schroom dus zeker niet om de dingen te zeggen die je niet goed vond gaan. Daarnaast vind ik het natuurlijk ook leuk om te horen wat je wel goed vond gaan.

Vind je het goed als ik een opname maak van dit interview? Dit maakt het voor mij makkelijker uit te werken. Achteraf zal ik het verslag naar je mailen zodat je het nog kunt aanpassen als ik iets verkeerd heb begrepen.

2. The decision aiding process

During this part of the interview a schematic overview of the process is presented to the interviewee to avoid ambiguity about specific parts of the process.

2.1. Involvement in the overall process

a. In hoeverre vond je dat je betrokken werd bij het zojuist geschetste proces?

b. In hoeverre voelde je je betrokken bij het proces van het komen tot het model?

c. Had je graag meer of minder betrokken willen zijn? Op welk punt?

2.2. Formulating the problem

a. Wat vond je van de manier waarop we het probleem gezamenlijk hebben geformuleerd?

b. Heb je nog tips voor het formuleren van het probleem?

2.3. Creating and validating the model

a. In hoeverre voelde je je betrokken bij het maken van het model?

b. Had je hier meer of minder betrokken bij willen zijn?

c. Hoe heb je de validatie sessie van het model ervaren?

d. Wat was voor jou het nut van deze validatie sessie?

e. Zou je, indien je het over kon doen, weer bij deze validatie sessie zijn?

f. Heb je nog tips voor het maken en valideren van het model?

2.4. The negotiation session

a. Hoe heb je de sessie ervaren?

b. Ik heb jullie bewust redelijk vrij gelaten, wat vond je hiervan?

c. Waren er punten waarop je graag meer sturing had gehad gedurende de sessie?

d. Wat zou je graag anders zien in deze resultaten sessie?

e. Heb je nog tips om deze sessie te verbeteren?

2.5. Confidence in the results

a. Herken je je in de resultaten van het onderzoek?

b. Hoe valide/betrouwbaar acht je de resultaten?

2.6. Balance impact and time

a. Als je terug kijkt naar de tijdsbesteding die je kwijt bent geweest, hoeveel was dit dan ongeveer?

b. Wat vond je van deze tijdsbesteding?

c. Wat is de maximale tijd die je kwijt zou willen zijn aan een dergelijk onderzoek?

d. Zou je, gegeven de impact van de resultaten van dit onderzoek, nogmaals de keuze maken om hieraan mee te werken?

e. Zou je een andere afdeling die kampt met de zelfde soort problemen ook aanraden dit te doen?

f. Hoe zie je de vervolgstappen van dit onderzoek?

g. Welke acties wil je ondernemen naar aanleiding van je nieuwe inzichten?

2.7. General

a. Heb je nog in het algemeen verbeterpunten voor het gehele proces?

3. Incease in situation awareness

a. Wat zijn de belangrijkste lessons learned die je mee neemt uit de resultaten van mijn afstudeeronderzoek? (oplossingen, effect oplossingen, trade-offs, mening anderen)

b. Welke inzichten heb je gekregen naar aanleiding van mijn afstudeeronderzoek?

c. Welke inzichten vind je het meest waardevol?

d. Op welke andere manier had je deze inzichten kunnen verkrijgen?

e. Had je nog graag andere inzichten willen krijgen, die je nu niet hebt gekregen?

f. Op welke manier had je nog meer inzichten kunnen krijgen?

g. Kun je aangeven waarin “deze manier van beslissingen nemen” anders is dan de manier waarop jullie normaliter een beslissing nemen?

h. Hoe helpen deze inzichten je in de praktijk?

4. Evaluation of the visualisation

During this part of the interview a printed version and digital version of the visualisation are presented to avoid ambiguity about specific elements of the graph.

4.1. Domain problem characterisation and general feedback

a. Had je wel eens eerder met een interactie visualisatie gewerkt?

b. Wat vond je van de manier waarop de resultaten waren weergegeven in de grafiek?

c. Wat was je eerste gedachte toen je de grafiek zag?

d. Hoe dacht je na 5 minuten over het gebruik van de grafiek?

e. Hoe lang had je nodig om de werking van de grafiek te ontdekken?

f. In hoeverre hielp de visualisatie om tot een keuze te komen voor een oplossing?

g. Welke inzichten heb je gekregen door de visualisatie?

h. Heb je nog verbeterpunten voor de visualisatie?

4.2. Task and data abstraction

a. Wat was voor jou het nut van de visualisatie?

b. Op welke manier had dit nut vergroot kunnen worden?

c. Welke informatie miste je om nog beter een beslissing te kunnen nemen?

4.2. Visual encoding

a. Welke aspecten/onderdelen van de grafiek vond je onduidelijk?

b. Welke aspecten/onderdelen van de grafiek vond je duidelijk?

c. Waren alle aspecten van de grafiek goed zichtbaar?

d. Zou je de volgende keer graag iets anders zien in de visuele weergave?

4.3. Interaction

a. Welke functionaliteiten van de grafiek vond je waardevol?

b. Welke functionaliteiten van de grafiek vond je overbodig?

c. Hoe moeilijk/makkelijk vond je het om zelf dingen in de grafiek aan te passen?

d. Had je graag andere mogelijkheden gehad om zelf dingen aan te passen? Zo ja, welke?

5. Value of the decision aiding approach for the department of operational excellence

This questions are only asked to employees of the operational excellence department. For the employees who were not involved during the project the method which is used is explained briefly.

5.1. Value of the approach in general

a. Wat zie jij als belangrijkste nut van het gebruik van MOO?

b. Wat vind je van de volgende stelling: “Ik zou MOO toevoegen aan de toolbox van de Blackbelt”? Waarom wel/niet?

c. Wat vind je van de volgende stelling: “Ik zou MOO in ieder Blackbelt project gebruiken”?

Waarom wel/niet?

d. Wat vind je van de volgende stelling: "Ik zou MOO als deel van een Blackbelt project gebruiken, niet als op zich zelf staand project"? Waarom wel/niet?

e. Op welk type vraagstuk/project zou je MOO gebruiken?

f. Mijn inschatting is dat je dit traject in 4-6 weken fulltime kunt doorlopen (afhankelijk van de complexiteit van de processen, agenda's van stakeholders en de beschikbaarheid van data). Wat vind je van deze tijdsbesteding? Vind je het het waard?

g. Indien we duurzame resultaten willen bereiken, is daar nog iets voor nodig van de methode?

h. Wat vind je van de volgende stelling: "De output van de MOO is eigenlijk te complex voor de stakeholders. Daarom moet de analyst de resultaten grondig analyseren en de decision makers in een bepaalde richting sturen"? Waarom wel/niet?

i. Wanneer is het gebruik van MOO een succes voor jou?

j. Heb je nog verbeterpunten waardoor MOO waardevoller/beter gebruikt kan worden door de Blackbelt?

5.2. Value of MOO, or simulation with deep uncertainty, compared to conventional simulation studies

a. Hoe zou je het verschil tussen MOO en een standaard simulatie studie beschrijven?

b. Wat zijn volgens jou de voordelen van MOO voor de Blackbelt ten opzichte van en normale simulatie studie?

c. Wat zijn volgens jou de nadelen van MOO voor de Blackbelt ten opzichte van en normale simulatie studie?

d. Wat vind je van de volgende stelling: "Nu ik me bewust ben van deze mogelijkheid, zou ik dit voortaan voor alle simulatiestudies gebruiken."?

e. Wat vind je van de volgende stelling: "Ik zou MOO alleen gebruiken als het niet meer tijd/resources kost dan een normale simulatiestudie"?

f. Bij welke type projecten is MOO extra waardevol vergeleken met een normale simulatiestudie?

6. Wrap up

a. Heb je nog opmerkingen of vragen die je graag kwijt wilt?

b. Bedankt voor je tijd.

C | Many-Objective Optimisation Algorithms

An important aspect of the execution of a many-objective optimisation is the algorithm which is used. Since the decision is made to focus on a posteriori decision making, traditional single objectives algorithms which produce one single optimal solution are not applicable. To be able to generate a set of Pareto optimal solutions a Multi-Objective Evolutionary Algorithm (MOEA) can be used. MOEAs are a type of optimisation algorithms which are inspired by the processes of natural evolution (Hadka and Reed, 2012a). The first generation of MOEAs performed well on optimisation problems with two or three objectives, but had difficulties handling more than three objectives (Hadka and Reed, 2012a). Enabled by increasing computation power, a number of MOEAs which focus on optimisation with more than three objectives has been developed since 2003. According to Deb (2010) the performance of a MOAE can be characterised by the convergence and the diversity. Convergence refers to the ability of the algorithm to find a set of Pareto approximate solutions that lie on or close to the true Pareto-optimal solutions (Chand and Wagner, 2015). Diversity refers to the ability of the algorithm to find a set of solutions that is diverse enough to represent the full range of the true Pareto front.

Within this research, one of the available MOEAs will be used to execute the optimisation. This section gives a brief overview of the current state-of-the-art MOEAs derived from literature. This is not an exhaustive overview as there are many methods and extensions which has been developed (Chand and Wagner, 2015). It does, however, function as a good basis for the selection of an algorithm. In the overview only algorithms are presented which have proven to perform well when more than three objectives are taken into account.

C.1 (ϵ-)NSGA-II

One of the most used algorithms in literature is the non-dominated sorting genetic algorithm II (NSGA-II) as proposed by Deb et al. (2002). It was originally used on optimisation problems with two or three objectives, but is has shown to be successful in problems with more objectives as well (Chand and Wagner, 2015). It uses a non-dominating sorting approach and has an explicit diversity-preserving mechanism. A benefit of NSGA-II is that it is computationally fast

(Chand and Wagner, 2015; Purshouse and Fleming, 2007). An improvement of the NSGA-II is the ϵ-NSGA-II. This algorithm combines NSGA-II with an ϵ-dominance archive, adaptive population sizing and time continuation to make it more efficient in handling a larger number of objectives (Chand and Wagner, 2015). The use of ϵ-dominance enables the user to specify the level of detail which they want to achieve in the optimisation (Kollat and Reed, 2007b). ϵ-NSGA-II has been successfully applied to different actual problems (Ferringer et al., 2009; Kasprzyk et al., 2012; Kollat and Reed, 2007b)

C.2 ϵ-MOEA

ϵ-MOEA also uses the concept of ϵ-dominance. It promotes solution diversity by not allowing more than one solution within a difference of ϵ. Since the ϵ-dominance is used, it has the capability to specify the desired precision. It is a steady-state algorithm, which means that only one individual in the population is evolved per step. Termination of the ϵ-MOEA is based on a user specified maximum run time (Kollat and Reed, 2006). Deb et al. (2003, p222) showed that the ϵ-MOEA *"achieves a comparable distribution to the clustered NSGA-II with a much less computational time"*.

C.3 Borg-MOEA

The Borg-MOEA uses the ϵ-MOEA as an underlying algorithm (Hadka and Reed, 2012a). It uses an auto-adaptive operator recombination, which solves the problem to select one operator recombination a priori. Operators which produce more successful solutions are rewarded by allowing that operator to produce more solutions, and operators which produce unsuccessful results are limited in its contribution. This enables to algorithms to adapt to the characteristics of a specific problem, which improves the search in many different problem domains (Chand and Wagner, 2015). The Borg-MOEA uses the adaptive population sizing of the ϵ-NSGA-II algorithm and ϵ-dominance. Hadka and Reed (2012b) compared the Borg-MOEA to nine other state-of-the-art algorithms and concluded that the it had a better performance than the other algorithms on higher dimensional problems.

C.4 Selection Criteria

The choice of algorithm for the optimisation in this research depends on the problem at hand as certain algorithms are better suited for certain types of problems. Important selection criteria are:

1. **Perform well with many objectives**: the problems at hand have about 10 objectives and the algorithm must be able to deal with this.

2. **Computationally efficient**: due to time constraints and limited computational power it is important that the algorithm operates efficient, also with many objectives.

3. **Short run-time**: besides being efficient also other options are possible to limit the run-time, such as the ability to execute runs in parallel.

4. **Available**: the algorithm should be available to use in an academic context.

Based on the selection criteria above, the ϵ-NSGA-II MOEA is selected. The main advantage of the ϵ-NSGA-II MOEA above the Borg-MOEA and ϵ-MOEA is that it has the ability to execute runs in parallel, which will drastically reduce the run time. Due to the limited available time for this research, this is seen as important. The performance of the Borg-MOEA and ϵ-NSGA-II is expected to be comparable. This results in the selection of the ϵ-NSGA-II MOEA.

D | Script Connecting Arena to Optimisation Algorithm

This appendix shows the python code which is used to connect the simulation model, created with Arena simulation software of Rockwell Automation, to the ϵ-NSGA-II algortihm. More information and practical tips on how to create the connection between Arena, the optimisation algorithm and the visualisation can be found in the ZIP file attached to this thesis.

```
'''
Created on Feb 3, 2017

@author: jhkwakkel
'''
from __future__ import division

import subprocess
import os

import xlrd
import xlwt

import numpy as np

from ema_workbench.em_framework.model import FileModel
from ema_workbench.em_framework.util import combine
from ema_workbench import ema_logging
from ema_workbench.util import EMAError
from ema_workbench.util.ema_logging import method_logger
from ema_workbench import (Scenario, IntegerParameter, CategoricalParameter)
from ema_workbench.em_framework.samplers import sample_levers
from ema_workbench.em_framework.outcomes import ScalarOutcome, AbstractOutcome
from ema_workbench.em_framework.ensemble import ModelEnsemble
from ema_workbench.util.utilities import save_results


class ArenaModel(FileModel):
    run_command = '{}\siman {}'
    file_name = 'input.xls'

    def __init__(self, name, write_input, parse_output, wd=None,
                 model_file=None, arena_dir=None):
        super(ArenaModel, self).__init__(name, wd=wd, model_file=model_file)
```

```
        if not os.path.exists(arena_dir):
            raise EMAError("arena not found")

        self.arena_dir = arena_dir
        self.parse_output = parse_output
        self.write_input = write_input

    @method_logger
    def run_model(self, scenario, policy):
        """
        Method for running an instantiated model structure.

        Parameters
        ----------
        scenario : Scenario instance
        policy : Policy instance


        """
        super(ArenaModel, self).run_model(scenario, policy)
        constants = {c.name:c.value for c in self.constants}
        experiment = combine(scenario, policy, constants)

        path_to_file = os.path.join(self.working_directory, self.model_file)
        if not os.path.isfile(path_to_file):
            raise ValueError('cannot find model file')
        run_command = self.run_command.format(self.arena_dir, path_to_file)

        # write input
        parameter_names = [u.name for u in self.uncertainties]
        parameter_names += [l.name for l in self.levers]
        parameter_names += [c.name for c in self.constants]
        parameters = [experiment[name] for name in parameter_names]
        self.write_input(self.working_directory, self.file_name, parameters)
        assert os.path.isfile(os.path.join(self.working_directory, self.file_name))

        # run
        ema_logging.debug(run_command, )
        with open(os.devnull, 'w') as devnull:
            subprocess.check_call(run_command, stdout=devnull)
#             subprocess.check_call(run_command)

        # parse output
        output = self.parse_output(self.working_directory)
        outcomes = {o.name:output[o.name] for o in self.outcomes}
#           ema_logging.info(outcomes)
        self.output = outcomes

def prepare_files(arenadir, model_dir, model_name):
    '''

    model_file_name : str, name without extension

    '''
```

```
    path_to_model = os.path.abspath(model_dir)

    assert(os.path.exists(path_to_model))
    assert(os.path.exists(arenadir))


    os.chdir(arenadir)

    p = subprocess.Popen("model {}\\{}.mod".format(model_dir,model_name),
                         stdin=subprocess.PIPE)
    p.communicate('\n')
    if p.returncode != 0:
        raise EMAError('siman model command failed')

    p = subprocess.Popen("expmt {}\\{}.exp".format(model_dir,model_name),
                         stdin=subprocess.PIPE)
    p.communicate('\n')
    if p.returncode != 0:
        raise EMAError('siman expmt command failed')


    p = subprocess.Popen("linker {0}\\{1}.m {0}/{1}.e".format(model_dir,model_name),
                         stdin=subprocess.PIPE)
    p.communicate('\n')
    if p.returncode != 0:
        raise EMAError('siman linker command failed')

def parse_output(wd):
        labels = ['gem. wachttijd per uur van call',
              'maximale wachttijd per dag van call',
              'wachttijd (dagen) per verzoek',
              'abandon rate call',
              'fte',
              'overuren',
              'kosten FTE',
              'kosten overuren',
              'switchen per dag',
              'tijd switchen per keer',
              'dagen overwerk',
              'druktemoment per dag']

        fn = os.path.join(wd, 'Output2.xls')
        assert(os.path.exists(fn))

        output = xlrd.open_workbook(fn)
        sheet = output.sheets()[0]

        data = {}
        for i in range(12):
            col = sheet.col(i)
            label  = labels[i]

            col = [entry.value for entry in col if entry.value != '']
            if not col:
                value = 0
```

```
            elif i ==2:
                n = len([entry for entry in col if entry==0])
                value = n/len(col)
            else:
                value = np.mean(col)

            data[label] = value

        return data

def write_input(wd, file_name, parameters):
    fn = os.path.join(wd, file_name)
    wb = xlwt.Workbook()

    sheet = wb.add_sheet('Blad1')

    for i, param in enumerate(parameters):
        sheet.write(0, i, param)
    wb.save(fn)


if __name__ == '__main__':
    ema_logging.log_to_stderr(ema_logging.DEBUG)

    arena_dir = r'C:\Program Files (x86)\Rockwell Software\Arena'
#   model_dir = r'C:\Users\jhkwakkel\Documents\model'
#   model_dir = r'C:\model'
    model_dir = r'C:\temp\model'
#   model_dir = r'Z:\Documents\workspace\EMAProjects\JAN\arena\model'
#   model_name = 'Model_final4'
    model_file = 'Model_4rep.p'


    model = ArenaModel('test', write_input, parse_output, wd=model_dir,
                       model_file=model_file, arena_dir=arena_dir)
    model.outcomes = [ScalarOutcome('gem. wachttijd per uur van call',
                        kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('maximale wachttijd per dag van call',
                      kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('wachttijd (dagen) per verzoek',
                      kind=AbstractOutcome.MAXIMIZE),
                      ScalarOutcome('abandon rate call'),
                      ScalarOutcome('fte'),
                      ScalarOutcome('overuren', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('kosten FTE', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('kosten overuren', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('switchen per dag', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('tijd switchen per keer', kind=AbstractOutcome.MAXIMIZE),
                      ScalarOutcome('dagen overwerk', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('druktemoment per dag', kind=AbstractOutcome.MINIMIZE)]

    model.levers = [IntegerParameter('length queue for more call', 0, 20),
                    IntegerParameter('percentage with client', 70, 100),
                    IntegerParameter('dummy', 0, 24),
                    CategoricalParameter('overwerk', [0, 1]),
```

```
                IntegerParameter('time to shift away from call', 20, 100)
                ]

ndesigns = 5000
policies = sample_levers(model, ndesigns)

ensemble = ModelEnsemble()
ensemble.model_structures = model
ensemble.policies = policies
ensemble.parallel = True
ensemble.processes = 2
results = ensemble.perform_experiments([Scenario({})], reporting_interval=1)

save_results(results, './output/{} 4 replications.tar.gz'.format(ndesigns))
```

E | Detailed Model Specification Case Study I

This appendix presents a detailed model specification of the discrete event model which is created in case I. First the model structure is discussed. Next, the specification of the model is discussed. Thereafter, the verification and validation of the model is explained.

E.1 Model Structure

The first case is executed at the The Service Desk Executors (SDE, *In Dutch: Service Desk Nabestaanden*). The SDE handles all customer contacts and requests related to deceased customers. An example of such a request is the termination of a bank account of a deceased customer. Within the SDE there are two sub departments: (1) SDE-Regular and (2) SDE-Specials. These sub departments handle different kinds of request. 'Standard requests' are handled by SDE-Regular, whereas more 'complicated requests' are handled by SDE-Specials. An example of a complicated request is when a deceased customer has multiple products of ING, such as a bank account and a loan or a mortgage. Each sub department is led by a 'CLT Lead' and an 'Agile Coach'. A 'Super Circle Lead' oversees the performance of multiple departments, so for example not only SDE, but also 'Loans' and 'Bankruptcies'.

This case study is focused on the sub department Regular. Every week the SDE-Regular receives over X customer requests and answers almost X calls.

The model contains four subsystems and is structured along the two main processes of the SDE: answering calls of customers (customer contact) and processing requests of customers (customer requests). Both processes represent a subsystem within the model. In addition, one subsystem is focused on the switching process between customer contact and customer requests. The fourth subsystem is not related to the processes of SDE but supports the working of the model, by for example collecting the output data and writing this to a CSV file. The four subsystems are discussed briefly. The model overview can be found in Figure E.1.

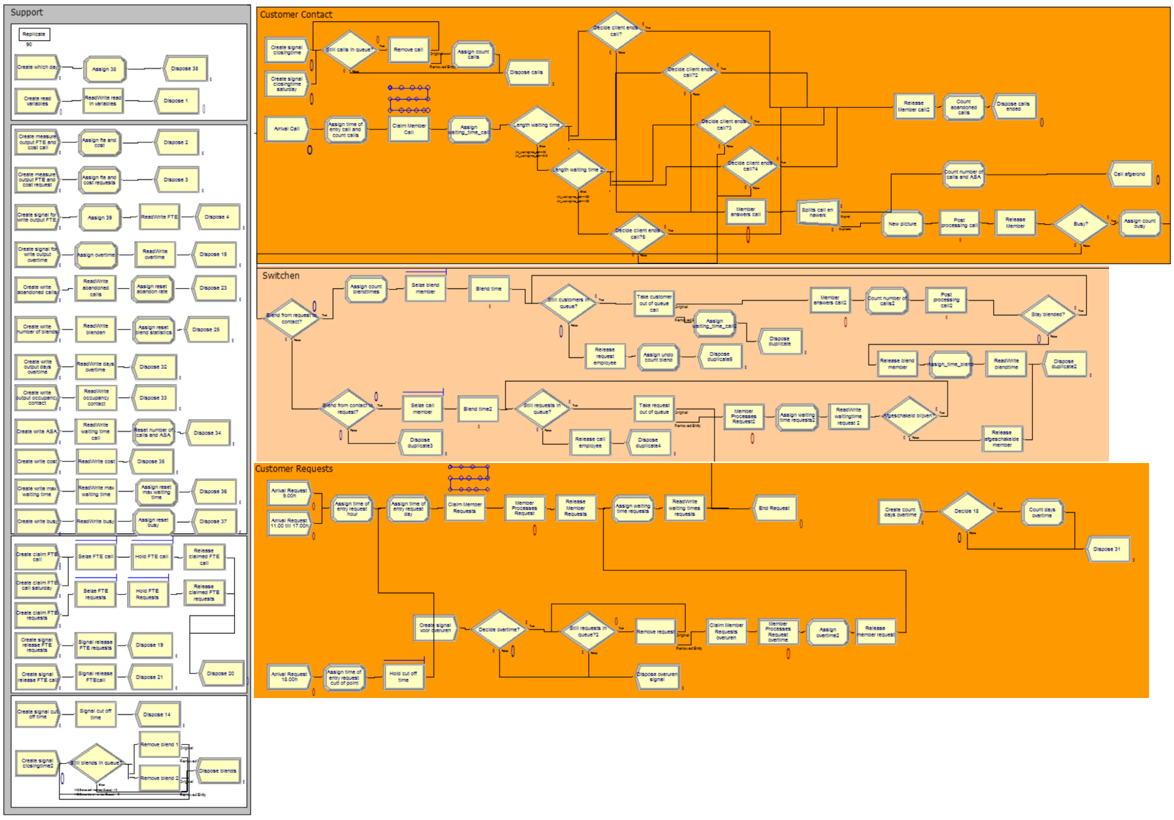


FIGURE E.1: Model overview SDE

E.1.1 Subsystem Customer Contact

The process of customer contact starts with the arrival of a call of a customer. The time of entry is assigned and the number of calls which arrived is counted. The call arrives in a queue to wait for a employee which can answer the phone. Based on the waiting time, a decision is made whether the customer abandones the call or not. If the customer did not abandon the call, the employee answers the call. After the call is answered, the call is disposed and the employee starts processing the call. After that, the employee is finished and is available to answer another call. After the employee is finished a duplicate of the call continues to the switching subsystem.

Within the subsystem customer contact a subsystem is present to indicate the closing time of the call process. The SDE can be reached by phone from 08.00h till 21.00h. All calls which are still in queue at 21.00h are removed. An overview of the subsystem customer contact can be found in Figure E.3.

E.1.2 Subsystem Customer Request

The process of customer requests starts with the arrival of requests. Requests can arrive via physical mail or e-mail. In the morning a peak in arrival happens since around 09.00h the physical mail arrives. All requests who arrive before a certain time are aimed to be processed the same day (TITO). When a request arrives, the arrival time is registered and the request arrives in a queue where it waits until an employee is available to process it. After the processing, the request is disposed and the employee is available to process a different request. Depending on the process variables, it can happen that not all requests are processed TITO. Overtime is necessary to process the requests TITO. At the end of the day, it is checked whether there are still requests in queue. If this is the case, overtime is necessary to process them. The hours and days overtime are counted. Note; if one day overtime is necessary, but the other the work is finished early, this compensates each other. An overview of this subsystem is presented in Figure E.4.

E.1.3 Subsystem Switching

After each call, this sub system is triggered. It is checked whether it is very busy on the phone and thus an employee who is working on requests should switch to customer contact, or vice versa. First, it is checked how many customers are in queue on the phone. If this is more than a specified number, an employee has to switch to customer contact. This switch takes some time. After the employee answered a phone call it is checked if it is still busy on the phone. If this is still the case, the employee keeps answering phone calls. If it is not busy anymore, the employee returns to requests. This exact same process, but vice versa, is in place for switching from customer contact. If there are no customer waiting, an employee starts processing requests until there are customer waiting in the call queue. An overview of the switching subsystem is given in Figure E.5.

E.1.4 Subsystem Support

The subsystem support makes sure the model works properly. Within this subsystem the different design variables are read in from the CSV file. In this way, the process design can be automatically changed which is necessary for the connection between the algorithm and Arena. In this part also the output variables (the objectives) are written to a CSV file. The algorithm combines the design variables and scores on the objectives to one line in the solution set. In addition to the reading and writing of variables, this subsystem also provides so signals such as closing time. The subsystem can be found in Figure E.6.

E.2 Model Specification

The model specification deals with the run set up, the input and output data and the most important assumptions of the model.

E.2.1 Run Setup

To run the model the run setup has to be specified. The run setup contains four elements:

1. Type of System

The system can have an open end or a closed end. In this case, the system has a closed end. The system has a clear start point and end point, being the start of the week at Monday morning and the end of the week at Saturday afternoon. The situation at Saturday afternoon is the same as Monday morning: all queues are empty. It might, of course, be the case that there is a large under-capacity which results in an inventory of requests at the end of Saturday, which causes the end situation to be different from the start situation. However, since this is undesired, overtime will be used to process this inventory before Saturday afternoon.

2. Warm-up Period

If the model contains parameters which have to stabilise a warm-up period can be used. This is not the case for this model. Therefore, no warm-up period is used.

3. Run time

The run time of the model is 90 hours. This derived from the working hours of the department; the department is open six days a week from 08.00h till 21.00h. To allow for overtime, the model assumes the department is open from 8.00h till 23.00h. This is 15 hours per day, times six days results in a run time of 90 hours.

4. Number of Replications

Using a simulation model has the advantage that particular uncertainty can be incorporated in the model. To obtain a proper and reliable estimate of the mean performance multiple replications have to be executed (Robinson, 2004). A different replication uses a different random number seed, resulting in different outcomes of the model (Hoad et al., 2007). The more replications, the more precise the model estimates are. However, simulation optimisation is an intensive method regarding computational power, so the number of replications should be limited to mitigate the risk on extreme long run times of the optimisation. However, to little replications make the results less reliable.

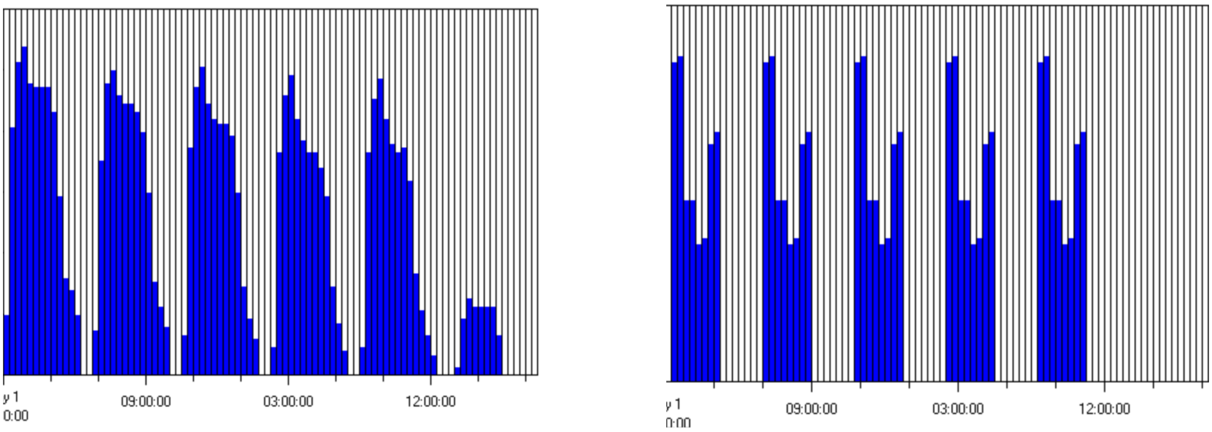
The minimum number of replications is calculated based on the confidence interval of the output variables. A test run is done with 4 replications. Based on this run the confidence intervals and half widths of the variables are determined. Not every variable has the same desired precision. For every variable it is checked how many replications are needed to reach the desired precisions with 95% confidence. The following formula is used to calculate the number of replication:

$$\bar{x} \pm 1.96 * \frac{\sigma}{\sqrt{n}}$$

Where $\bar{x}$ is the average, σ the standard deviation and n the number of replications. Based on the desired half width, n can be calculated. This resulted in a number of replications of 14.

E.2.2 Input Data

Most important input data is the inflow of calls and request. This data was available since this is collected every day. The inflow of calls can be found in Figure E.2b and the inflow of e-mail requests can be found in Figure E.2a. Every morning around 09.00h the physical mail is delivered. This is not incorporated in the schedule, since all mail arrives at the same point in time and not spread over the hour.



(a) Arrival schedule calls SDE

(b) Arrival schedule requests SDE

Figure E.2: Arrival schedules SDE

In addition, important input variables are the variables which are changed to generate different solutions. These variables can be found as 'design variables' in Table E.1. The metrics of the variables can be found in Table E.2. The value of the design variable is read in though a 'read-write module' from a CSV file.

E.2.3 Output Data

The most important output data is the performance on the objectives. The objectives can be found in Table E.1. The performance is pushed to a CSV file through a 'read-write module'. The metrics of the output variables can be found in Table E.2.

E.2.4 Most Important Assumptions

The most important assumptions are:

- Inflow of calls and requests is based on the average inflow of the past three months. Extreme situations, such as system breakdowns, are not incorporated in the inflow.
- When an employee is scheduled on customer contact, but there are no customers in queue, he/she starts processing requests.

Perspective	Objective	Translation to structured formulation
Client	Low waiting time on the phone	Low Average Speed of Answer (ASA) Low maximum waiting time Low abandon rate
	Low processing time of requests	Low average waiting time for the processing of a request Today In = Today Out (TITO)
Employee	Little work pressure on the phone	Not too much customers in the call-queue
	Little overtime	Not too much hours overtime Not too frequently having to work overtime
	Not too much switching	Not switching too often Not switching for a short amount of time
Cost	Low personnel cost	Stay within overall budget
	Low cost overtime	Stay within overall budget
Design variables	Human capacity	Number of FTE, fixed and flexible, available
	Percentage customer time	The percentage the employee spends on customer related tasks
	Switching dynamics	When to switch employee from customer request to customer contact When to switch employee from customer contact to customer request

Table E.1: Structured overview of input and output variables

- When an employee processes requests while he/she is scheduled on customer call, he/she processes the easier and shorter requests. If an employee is scheduled on requests, he/she processes the harder, longer requests, unless there are only easy requests waiting. On average an employee processes X requests per hour.

- Employees are scheduled on customer contact between 08.00h - 21.00h. Employees are scheduled on customer requests from 09.00h - 19.00h.

- The time it takes to switch from customer requests to customer contact is on average 1 minute, with a standard deviation of 0.5 minute.

- It is not possible that all employees who are scheduled on customer call are processing requests, since always one employee has to be immediately available. It is possible that all employees scheduled on customer requests switch to customer contact when it is very busy on the phone.

- When an employee has to work overtime the one day, but is able to leave early another day, this compensates each other.

- The ratio fixed personnel versus flexible personnel is X:X.

Variable	Metric
Low Average Speed of Answer (ASA)	Average of ((answer time − arrival time)*60*60) [second]
Low maximum waiting time	Maximum of ((answer time − arrival time)*60*60) [second]
Low abandon rate	Average of daily percentage of (number of abandoned call / total number of calls)*100 [%]
Today In = Today Out (TITO)	(number of requests processes the same day / total number of requests)*100 [%]
Not too much busy moments	# times more than X customer in queue [#]
Not too much hours overtime	# hours per week [#]
Not too frequently having to work overtime	# days per week [#]
Not switching too often	average of # switching per day [#]
Not switching for a short amount of time	average time in switched mode [min]
Low personnel cost	(# FTE * X * X) + (# FTE * X * X * X * X) [€ /year]
Low cost overtime	# hours overtime * X * 52 [€ /year]
Human capacity	# FTE [X-X#]
Percentage customer time	percentage spend on customer contact or requests X-X%]
TITO or not TITO	Require overtime to reach 100% TITO [1=yes, 0=no]
When to switch employee from customer request to customer contact	number of customers in line [X-X#]
When to switch employee from customer contact to customer request	ASA [X-X sec]

Table E.2: Metrics of input and output variables (confidential)

E.3 Model Verification

The verification ensures whether the model is correctly coded and no large differences exist between the qualitative model and the quantitative model. Two tests will be done: an input test and an output test.

E.3.1 Input test

In the input test it is checked whether the input data is correctly modelled in the model. This is done by comparing the inflow of the model with the average real inflow. Due to the incorporation of uncertainty in the model, the value can slightly differ. When the values differ maximum 5%, the value is assumed to be correct. The values can be found in Table E.3. Both value differ less than 5%, so it is assumed that it is modelled correctly.

	Deviation [%]	Inflow according to data
Number of calls	3%	X
Number of requests	1%	X

Table E.3: Input test SDE (confidential)

E.3.2 Output test

During the output test it is checked whether all entities which flow in the system also flow out of the system. It is undesired that entities remain in the system due to errors in the coding. Dummy entities are entities which are not real inflow, but entities which support the working of the model, by for example indicating a signal. The value for the number is calls is twice as much as the real inflow due to a duplication module, which is necessary to split the call itself and the after processing of the call. It turns out that all entities flow properly through the system. The values can be found in Table E.4.

	Inflow	Outflow
Number of calls	X	X
Number of requests	X	X
Dummy entities	X	X

Table E.4: Output test SDE (confidential)

E.4 Model Validation

The model validation aims to ensure that the model properly represents the real world. The validation is done using three types of validation tests: a reflective validation, a structural validation and an expert validation.

E.4.1 Reflective Validation

The first validation step is to check whether the model corresponds to the observed reality. To do this, all design variables, such as capacity and customer time, are set to the values as they currently are. It is checked whether the performance on the objectives corresponds to the performance which currently is observed. Not on all objectives a score is currently available. It is for example not counted how often more than X customers are in queue. However, the test is done based on the performance scores which are currently known. The comparison can be seen in Table E.5. It can be seen that all values are quite close to the observed values. Some slight differences are seen, but in general the scores correspond well. Only the maximum waiting time is slightly high. This is something to take into account when using the results.

E.4.2 Structural Validation

In addition to checking whether the model as is corresponds to reality, it is checked whether the model responds as expected when values are changed to extreme values. For example, if there

	Result from model	Observed value
ASA	X sec	X sec
Maximum waiting time	X sec	X sec
Abandon rate	X %	X %
Cost for personnel	X million	X million

Table E.5: Reflective validation SDE (confidential)

is almost no inflow of calls, will the waiting time on the phone be low? Or is the inflow is very high, will the waiting time be very high? Three different tests are done: (1) very low inflow of calls, (2) very high inflow of requests, (3) very high capacity. It is expected that when the inflow of calls is very low, the average waiting time, maximum waiting time and abandon rate are low. It is expected that when the inflow of requests is very high, much overtime is required given the current capacity. When the capacity is very high, it is expected that the waiting time on the phone is low, and no overtime is necessary. The model behaves as expected.

Test I: Low inflow of calls		
	Normal inflow call	Extreme low inflow call
ASA	X sec	X sec
Maximum waiting time	X sec	X sec
Abandon rate	vtextitX%	X%
Test II: High inflow requests		
	Normal inflow requests	Extreme high inflow call
Overtime	X hours	X
Test III: High capacity		
	Normal capacity	Extreme high capacity
ASA	X sec	X sec
Maximum waiting time	X sec	X sec
Abandon rate	X %	X %
Overtime	X hours	X hours
Personnel cost	X million	X million

Table E.6: Structural validation (confidential)

E.4.3 Expert Validation

The expert validation is seen as very important to check whether the model corresponds with reality and to check whether there might be errors in the qualitative or quantitative models. A session is organised with all involved decision makers to do an expert validation. In addition, this session is used to gain trust of the decision makers in the model and to explain the working of the model.

The expert validation resulted to some very valuable insights and changes to the model. The most important changes are described below. In addition, the assumptions, input and output data were confirmed once the changes were incorporated.

- Arrival of requests should be spread over the hours, and not be based on the requests are divided amongst the teams
- Schedule on requests runs till Xh, not till Xh
- After processing of a call is X seconds in stead of$X$ seconds. X is desired, but not realistic at the moment.
- Switching back is done based on the ASA, not on the number of customers in queue.
- The tasks which do not fall under the norm of X requests per hour should be incorporated in the FTE calculation.

E.5 Optimisation Problem Formulation

The final step of the creation of the simulation optimisation model is the formulation of the optimisation problem. In this formulating, the ranges of the input variables are defined, it is stated whether the objectives should be minimised or maximised, and the desired precision is determined. The input ranges are formulated in the model levers, the objectives in the model outcomes and the designed precision in the variable 'reporting interval'. The number of designs is chosen to be 5000. More designs would be desired, but this value presents a large and diverse enough solution set within the available computational power. The problem formulation is as follows:

```
model.outcomes = [ScalarOutcome('gem. wachttijd per uur van call',
                      kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('maximale wachttijd per dag van call',
                      kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('wachttijd (dagen) per verzoek',
                      kind=AbstractOutcome.MAXIMIZE),
                      ScalarOutcome('abandon rate call'),
                      ScalarOutcome('fte'),
                      ScalarOutcome('overuren', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('kosten fte', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('kosten overuren', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('switchen per dag', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('tijd switchen per keer', kind=AbstractOutcome.MAXIMIZE),
                      ScalarOutcome('dagen overwerk', kind=AbstractOutcome.MINIMIZE),
                      ScalarOutcome('druktemoment per dag', kind=AbstractOutcome.MINIMIZE)]

    model.levers = [IntegerParameter('length queue for more call', X, X),
                    IntegerParameter('percentage with client', X, X),
                    IntegerParameter('dummy', X, X),
                    CategoricalParameter('overwerk', [0, 1]),
                    IntegerParameter('time to shift away from call', X, X)
                    ]

    ndesigns = 5000
    results = ensemble.perform_experiments([Scenario({})], reporting_interval=1)
```

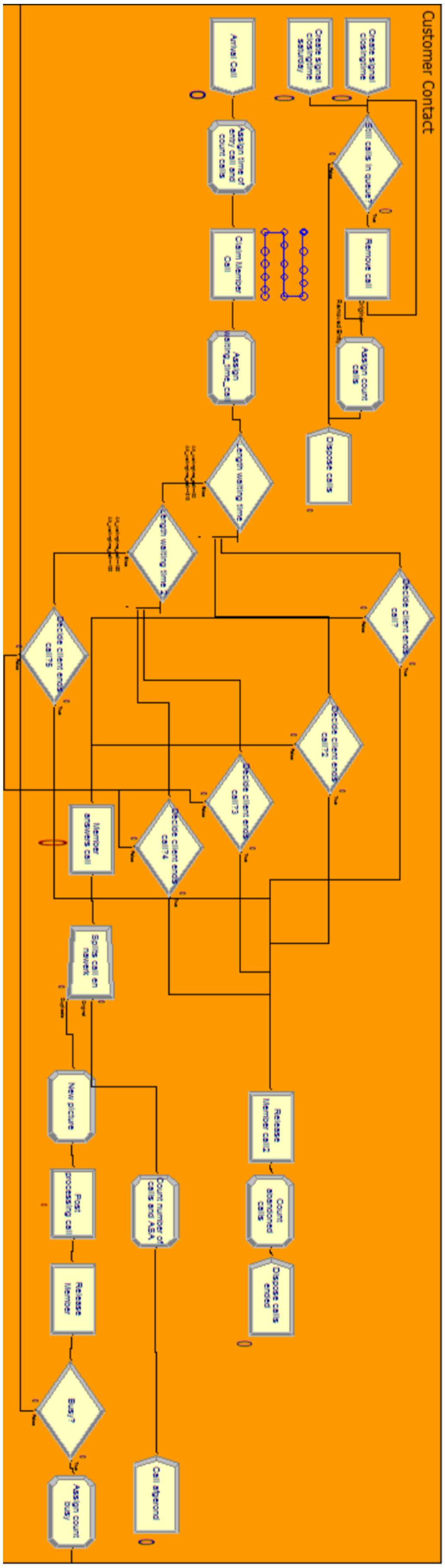


FIGURE E.3: Subsystem Customer Contact SDE

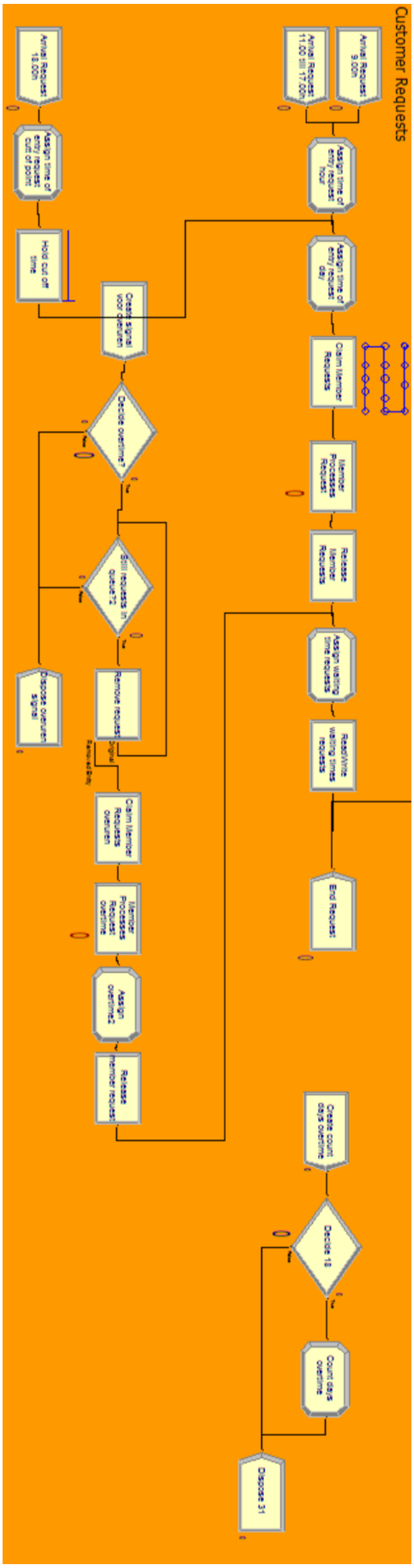


Figure E.4: Subsystem Customer Request SDE

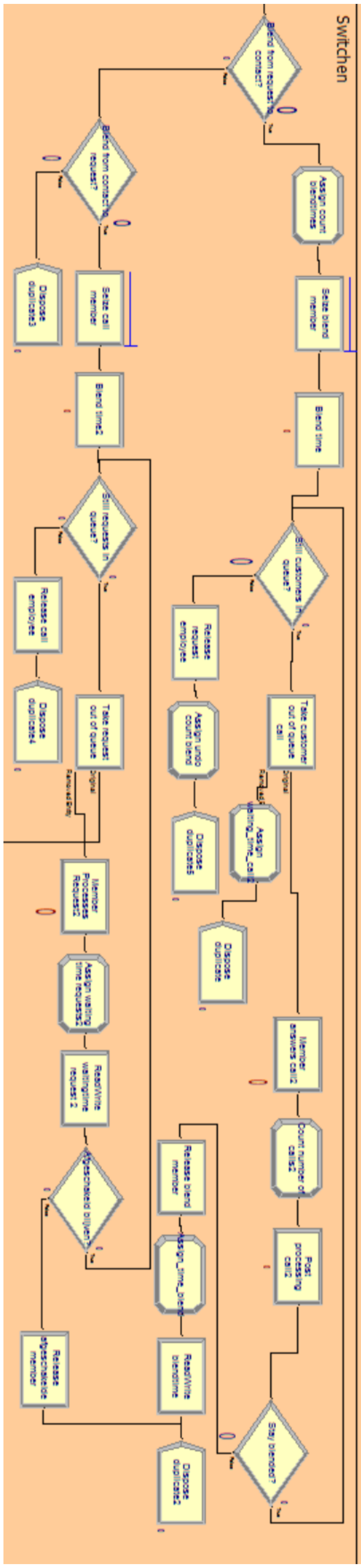


FIGURE E.5: Subsystem Switching SDE

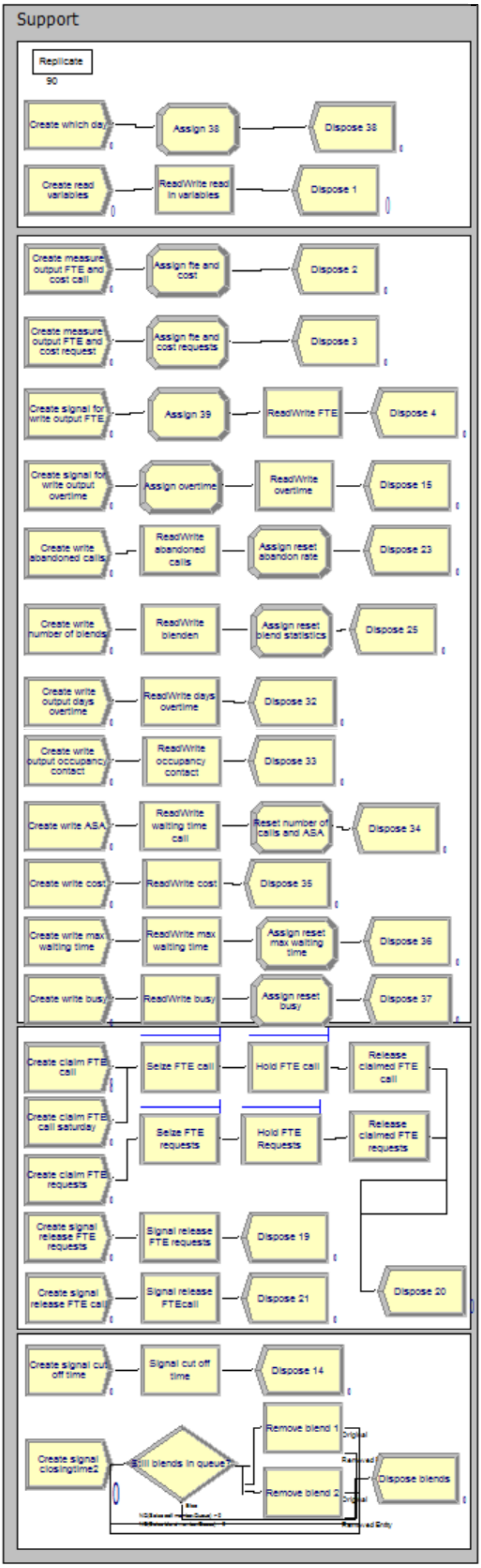


FIGURE E.6: Subsystem Support SDE

F | Detailed Model Specification Case Study II

This appendix presents a detailed model specification of the discrete event model which is created in case II. The model overlaps partially with the model from case I. Therefore, not everything is explained in full detail. Again, first the model structure is discussed. Next, the specification of the model is discussed. Thereafter, the verification and validation of the model is explained.

F.1 Model Structure

The second case study is conducted at The Department of Distresses & Bankruptcies (DDB, *In Dutch: Afdeling Beslagen & Faillissementen*). This department processes all financial distresses and bankruptcies and maintains contact with the customers of ING and other legal parties who are affected by this. An example of a task which is executed by the DDB is to block a bank account of a customer upon which a bailiff laid a distress. It is important to block the account as fast as possible to mitigate the financial risk for the bank. The department is led by a 'CLT Lead' and an 'Agile Coach'. Since 90% of the work of the department is related to distresses, this process is the focus of this case study. Every month the departments processes X customer requests and answers over X calls.

The model contains four subsystems and is structured along the two main processes of the DDB: answering calls of customers (customer contact) and processing requests of customers (customer requests). Both processes represent a subsystem within the model. In addition, one subsystem is focused on the switching process between customer contact and customer requests. The fourth subsystem is not related to the processes of DDB but supports the working of the model, by for example collecting the output data and writing this to a CSV file. The four subsystems are discussed briefly. The model overview can be found in Figure F.1.

F.1.1 Subsystem Customer Contact

This subsystem works the same as in the SDE model, only the durations of the processes differ. The process of customer contact starts with the arrival of a call of a customer. The time of entry is assigned and the number of calls which arrived is counted. The call arrives in a queue

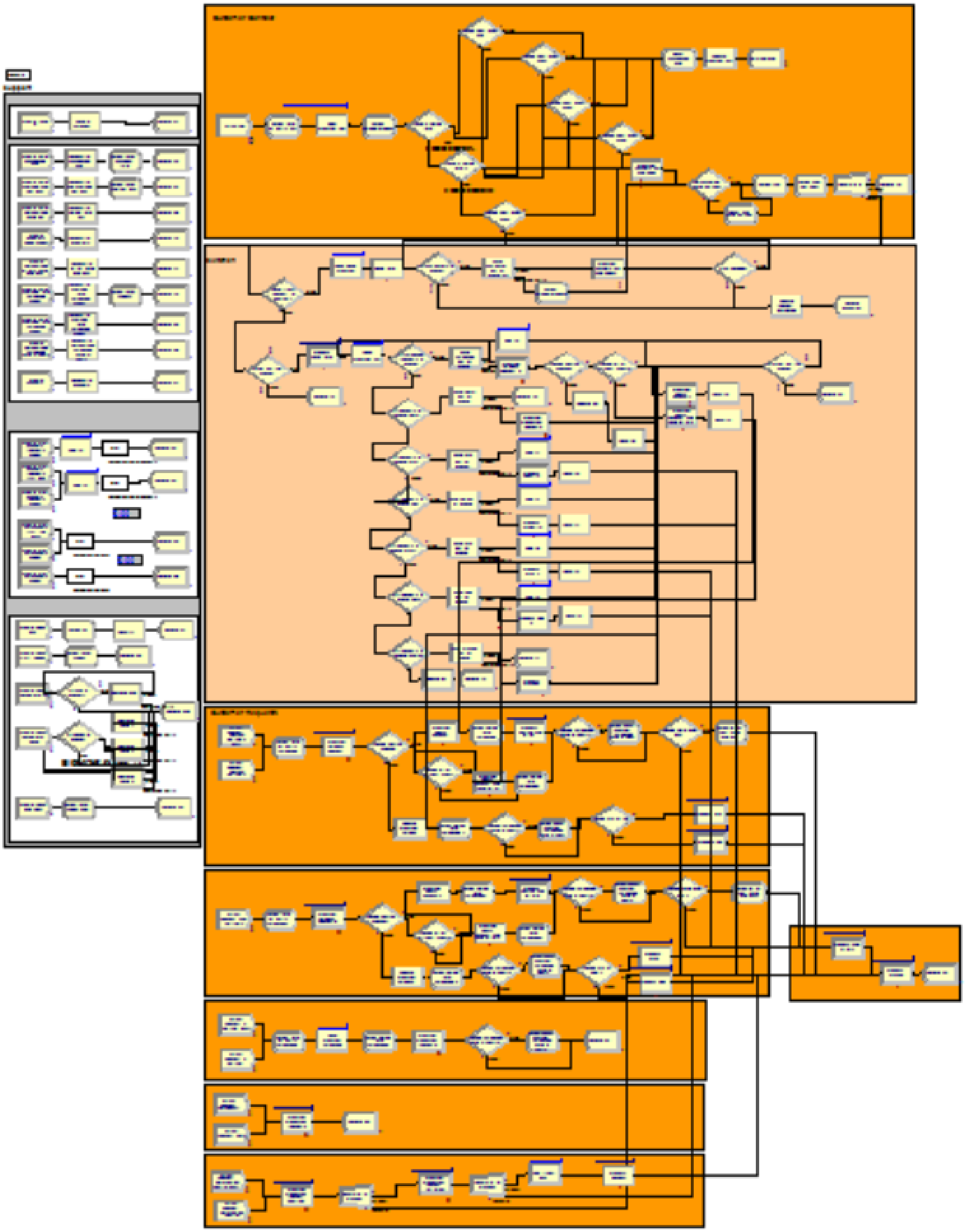


FIGURE F.1: Model overview DDB

to wait for a employee which can answer the phone. Based on the waiting time, a decision is made whether the customer abandons the call or not. If the customer did not abandon the call, the employee answers the call. After the call is answered, the call is disposed and the employee starts processing the call. After that, the employee is finished and is available to answer another call. After the employee is finished a duplicate of the call continues to the switching subsystem.

Within the subsystem customer contact a subsystem is present to indicate the closing time of the call process. The DDB can be reached by phone from 09.00h till 17.00h. All calls which are still in queue at 17.00h are removed. An overview of the subsystem customer contact can be found in Figure F.3.

F.1.2 Subsystem Customer Request

The process of customer requests starts with the arrival of requests. Requests can arrive via physical mail or e-mail. Different types of requests have different work flows, so they are modelled in different subsystems. For most work flows, the inflow at day 1 of the model is to be arrive at the beginning of the day, so there is a certain inventory they can work from. For the subsequent days, the inflow is spread over the days. Many of the work flows are connected with the archive work flow. In this work flow, all requests are archived. Not all type of requests have the same priority. An overview of the customer requests subsystem can be found in Figure F.4

F.1.3 Subsystem Switching

After each call, this sub system is triggered. It is checked whether it is very busy on the phone and thus an employee who is working on requests should switch to customer contact, or vice versa. First, it is checked how many customers are in queue on the phone. If this is more than a specified number, an employee has to switch to customer contact. This switch takes some time. After the employee answered a phone call it is checked if it is still busy on the phone. If this is still the case, the employee keeps answering phone calls. If it is not busy anymore, the employee returns to requests. This exact same process, but vice versa, is in place for switching from customer contact. If there are no customer waiting, an employee starts processing requests until there are customer waiting in the call queue. Not all types of requests are done in the switching time. The tasks, in sequence of priority, are: screening, BGV, GE, NA, archive. An overview of the switching subsystem is given in Figure F.5.

F.1.4 Subsystem Support

Also in this model there is a support part present. The subsystem support makes sure the model works properly. Within this subsystem the different design variables are read in from the CSV file. In this way, the process design can be automatically changed which is necessary for the connection between the algorithm and Arena. In this part also the output variables (the objectives) are written to a CSV file. The algorithm combines the design variables and scores on the objectives to one line in the solution set. In addition to the reading and writing of variables, this subsystem also provides so signals such as closing time. The subsystem can be found in Figure F.6.

F.2 Model Specification

The model specification deals with the run set up, the input and output data and the most important assumptions of the model.

F.2.1 Run Setup

To run the model the run setup has to be specified. The run setup contains four elements:

1. Type of System

For case II, the system has a closed end. The system has a clear start and end point, being the start of the months at the 23rd and the end of the month at the 22nd. The situation at the beginning of the month is the same as at the end of the month, or at least, that is desired; no inventory of requests. It might, of course, be the case that there is a large under-capacity which results in an inventory of requests at the end of the month, which causes the end situation to be different from the start situation. It is desired to measure this, so this is taken into account in the objectives.

2. Warm-up Period

If the model contains parameters which have to stabilise a warm-up period can be used. This is not the case for this model. Therefore no warm-up period is used.

3. Run time

The run time of the model is 308 hours. This derived from the working hours of the department; the department is open five days a week from 07.00h till 20.00h. To allow for overtime, the model assumes the department is open from 8.00h till 21.00h. This is 14 hours per day, times 22 days (22 working days in one month) results in a run time of 308 hours.

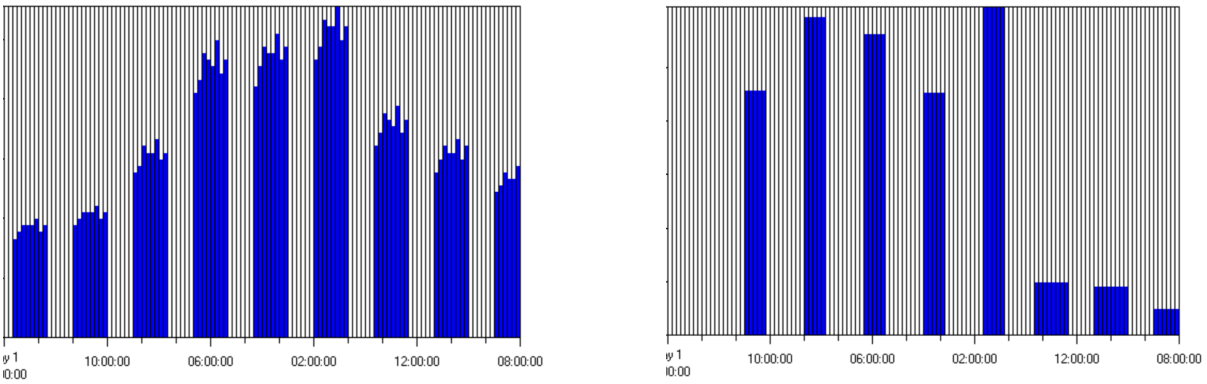
4. Number of Replications

The same method as in case I is used to calculate the number of replications. This resulted in a number of 4 replications.

F.2.2 Input Data

Most important input data is the inflow of calls and request. This data was available since this is collected every day. The inflow of requests in split in the different types of requests. Important to take into account is the peak inflow in the first week. Part of the inflow of calls can be found in Figure F.2a and an part of the inflow of physical requests can be found in Figure F.2b.

In addition, important input variables are the variables which are changed to generate different solutions. These variables can be found as 'design variables' in Table F.1. The metrics of



(A) Part of arrival schedule calls DDB

(B) Part of arrival schedule requests DDB

FIGURE F.2: Example of arrival schedules DDB

the variables can be found in Table E.2. The value of the design variable is read in though a 'read-write module' from a CSV file.

F.2.3 Output Data

The most important output data is the performance on the objectives. The objectives can be found in Table F.1. The performance is pushed to a CSV file through a 'read-write module'. The metrics of the output variables can be found in Table F.2.

F.2.4 Most Important Assumptions

The most important assumptions are:

- Inflow of calls and requests is based on the average inflow of the past three months. Extreme situations, such as system breakdowns, are not incorporated in the inflow.
- The model excludes inflow of Bankruptcies requests
- When an employee processes requests while he/she is scheduled on customer call, he/she processes the easier and shorter requests. If an employee is scheduled on requests, he/she processes the first screening, then bgv, then GE, then NA, then archive.
- Employees are scheduled on customer contact between 09.00h - 17.00h. Employees are schedules on customer requests from 07.00h - 18.00h.
- In peak week, employees can be scheduled on requests till 20.00h.
- The time it takes to switch from customer requests to customer contact is on average 1 minute, with a standard deviation of 0.5 minute.
- It is not possible that all employees who are scheduled on customer call are processing requests, since always one employee has to be immediately available. It is possible that

Perspective	Objective	Translation to structured formulation
Customer	Low waiting time on the phone	Low Average Speed of Answer (ASA) Percentage calls answered within X sec Low abandon rate
	Quick communication	No inventory at the start of peak week Quick communication with the customer when account is blocked
Risk	Fast screening of distresses	Low average time till screening in peak week Low average time till screening in normal week Percentage requests screened within X hours
Capacity	Effective and efficient use of capacity	A suitable capacity
Design variables	Capacity peak week customer contact	Number of hours available during peak week for customer contact
	Capacity normal week customer contact	Number of hours available during normal weeks for customer contact
	Capacity peak week customer requests	Number of hours available during peak week for customer requests
	Capacity normal week customer requests	Number of hours available during normal weeks for customer requests
	Switching dynamics	When to switch employee from customer request to customer contact When to switch employee from customer contact to customer request

TABLE F.1: Structured overview of input and output variables DDB (confidential)

all employees scheduled on customer requests switch to customer contact when it is very busy on the phone.

- The ratio customer time versus non customer time is X - X.

F.3 Model Verification

As in case I, two tests are done: an input test and an output test.

F.3.1 Input test

The values can be found in Table F.3. Both value differ less than 5%, so it is assumed that it is modelled correctly.

Variable	Metric
Low Average Speed of Answer (ASA)	Average of ((answer time − arrival time)*60*60) [second]
Percentage calls answered within X sec	(Number of calls with waiting time lower than X sec / total number of calls) * 100 [%]
Low abandon rate	Average of daily percentage of (number of abandoned call / total number of calls)*100 [%]
No inventory at the start of peak week	# number of requests in queue at the end of month * processing time request [hour]
Quick communication with the customer when account is blocked	# (letters sent the same day / total number of letters sent)*100 [%]
Low average time till screening in peak week	Average of (time processed âĂŞ arrival time) [hour]
Low average time till screening in normal week	Average of ((time processed âĂŞ arrival time)*60) [min]
A suitable capacity	(number of hours spend on customer contact + customer requests)/X [hour]
Capacity peak week customer contact	Hours scheduled in comparison with current situations [X - X]
Capacity normal week customer contact	Hours scheduled in comparison with current situations [X - X]
Capacity peak week customer request	Hours scheduled in comparison with current situations [X - X]
Capacity normal week customer requests	Hours scheduled in comparison with current situations [X - X]
When to switch employee from customer request to customer contact	Number of customers in line [X-X#]
When to switch employee from customer contact to customer request	ASA [X-X sec]

Table F.2: Metrics of input and output variables DDB (confidential)

	Deviation [%]	Inflow according to data
Number of calls	1%	X
Number of requests	2%	X

Table F.3: Input test BF (confidential)

F.3.2 Output test

The value for the number is calls is twice as much as the real inflow due to a duplication module, which is necessary to split the call itself and the after processing of the call. It turns out that all entities flow properly through the system. The values can be found in Table F.4.

F.4 Model Validation

The same type of validation tests are done as in case I.

	Inflow	Outflow
Number of calls	X	X
Number of requests	X	X
Dummy entities	X	X

Table F.4: Output test BF (confidential)

F.4.1 Reflective Validation

Not on all objectives a score is currently available. It is for example not counted what percentage letters is sent within one day. However, the test is done based on the performance scores which are currently known. The comparison can be seen in Table F.5. It can be seen that all values are quite close to the observed values. Some slight differences are seen, but in general the scores correspond well. Only the ASA is slightly low. This is something to take into account when using the results.

	Result from model	Observed value
ASA	X sec	X sec
Percentage within X sec	X%	X%
Abandon rate	X%	X%
Capacity	X hour	X hour

Table F.5: Reflective validation BF (confidential)

F.4.2 Structural Validation

Three different tests are done: (1) very low inflow of calls, (2) very high inflow of requests, (3) very high capacity. It is expected that when the inflow of calls is very low, the average waiting time, the percentage within X seconds and abandon rate are low. It is expected that when the inflow of requests is very high, the waiting time of requests is very high given the current capacity. When the capacity is very high, it is expected that the waiting time on the phone is low, and no inventory is present. Table F.6 presents the results of the structural validation. The model behaves as expected.

F.4.3 Expert Validation

The main insights of the expert validation were the following:

- The priority of tasks in switch mode was switched to
- Peak week does not take five days, bur four and a half
- Peak week starts on the 24th in general
- Waiting time screening would be split in peak week and normal week

The insights are taken into account in the model.

Test I: Low inflow of calls		
	Normal inflow call	Extreme low inflow call
ASA	X sec	X sec
Percentage within X sec	$X\%$	$X\%$ %
Abandon rate	$X\%$	$X\%$
Test II: High inflow requests		
	Normal inflow requests	Extreme high inflow call
Waiting time requests	X hours	X hours
Test III: High capacity		
	Normal capacity	Extreme high capacity
ASA	X sec	X sec
Percentage within X sec	$X\%$	$X\%$
Abandon rate	$X\%$	$X\%$
Inventory	X hours	X hours
Capacity	X hours	X hours

Table F.6: Structural validation DDB (confidential)

F.5 Optimisation Problem Formulation

The problem formulation is as follows:

```
model.outcomes = [ScalarOutcome('ASA [sec]', kind=AbstractOutcome.MINIMIZE),
                  ScalarOutcome('\% binnen X sec', kind=AbstractOutcome.MAXIMIZE),
                  ScalarOutcome('abandon rate', kind=AbstractOutcome.MINIMIZE),
                  ScalarOutcome('werkvoorraad [uren]', kind=AbstractOutcome.MINIMIZE),
                  ScalarOutcome('\% brieven zelfde dag', kind=AbstractOutcome.MAXIMIZE),
                  ScalarOutcome('wachttijd screenen bweek1', kind=AbstractOutcome.MINIMIZE),
                  ScalarOutcome('wachttijd screenen bweek2', kind=AbstractOutcome.MINIMIZE),
                  ScalarOutcome('\% screenen binnen X uur', kind=AbstractOutcome.MAXIMIZE)]

model.levers = [RealParameter('Percentage klanttijd', X, X),
                RealParameter('Verandering call bweek', X, X),
                RealParameter('Verandering call nweek', X, X),
                RealParameter('Verandering request bweek', X, X),
                RealParameter('Verandering request nweek', X, X),
                RealParameter('Bijschakelen', X, X),
                CategoricalParameter('Afschakelen', [x for x in range(X, X, X)]),
                IntegerParameter('Direct brief', X, X)
                ]

ndesigns = 100000
results = ensemble.perform_experiments([Scenario({})], reporting_interval=1)
```

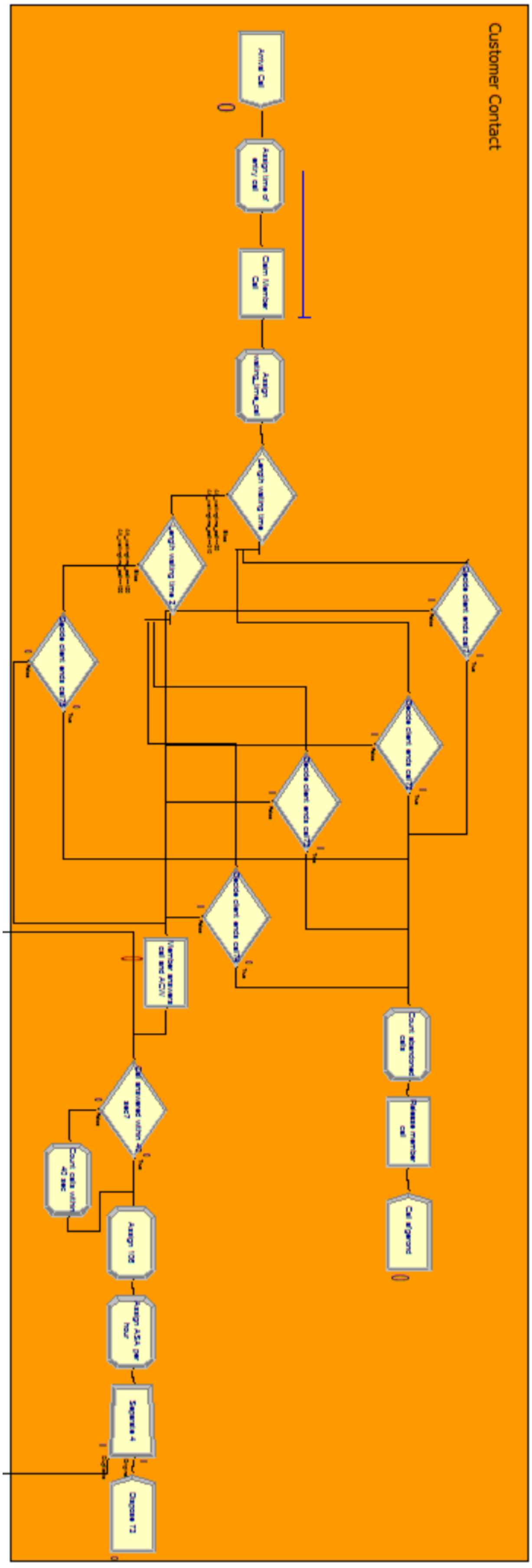


Figure F.3: Subsystem Customer Contact DDB

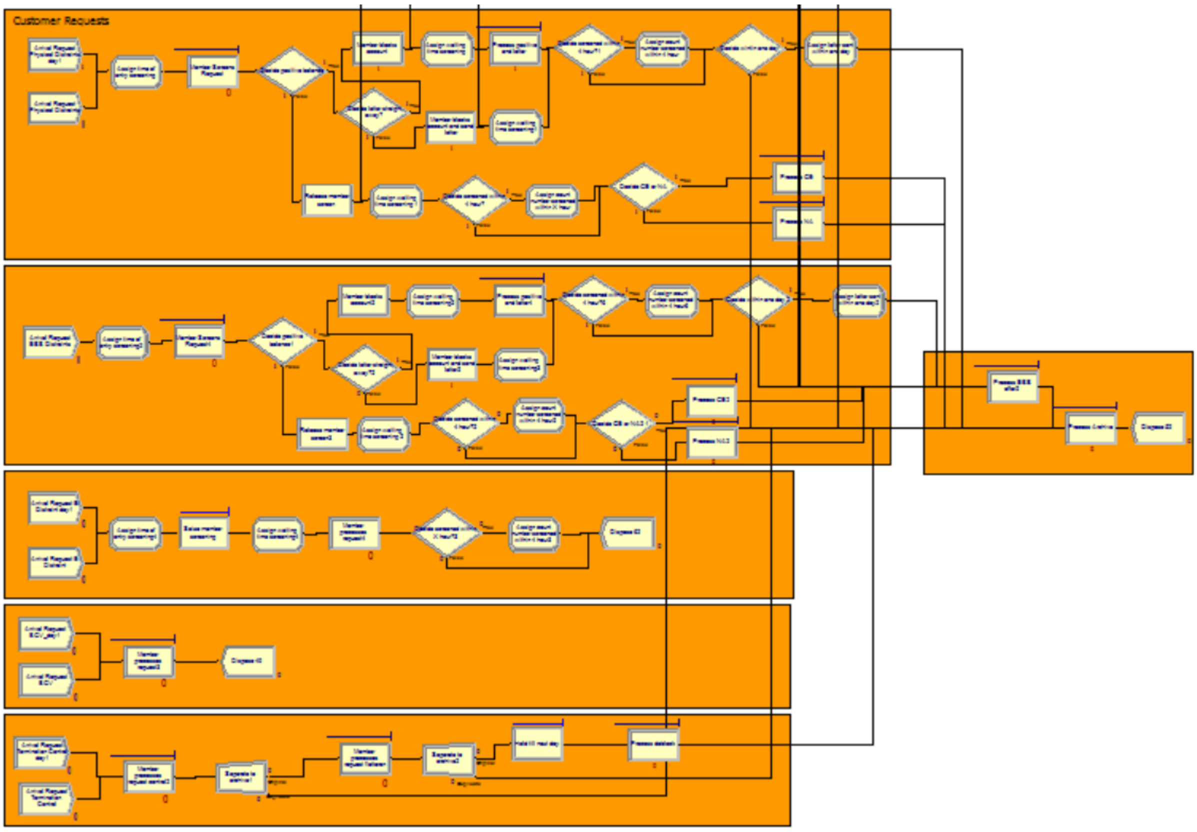


Figure F.4: Subsystem Customer Request DDB

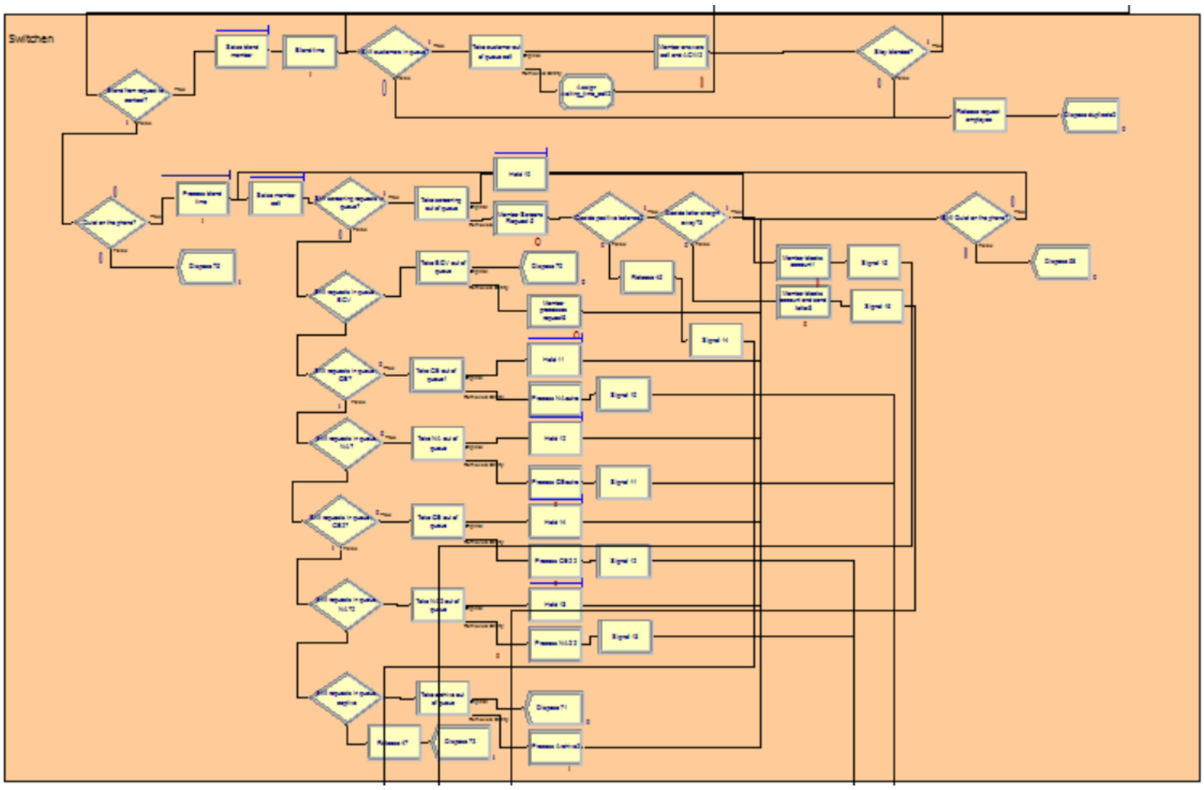


Figure F.5: Subsystem Switching DDB

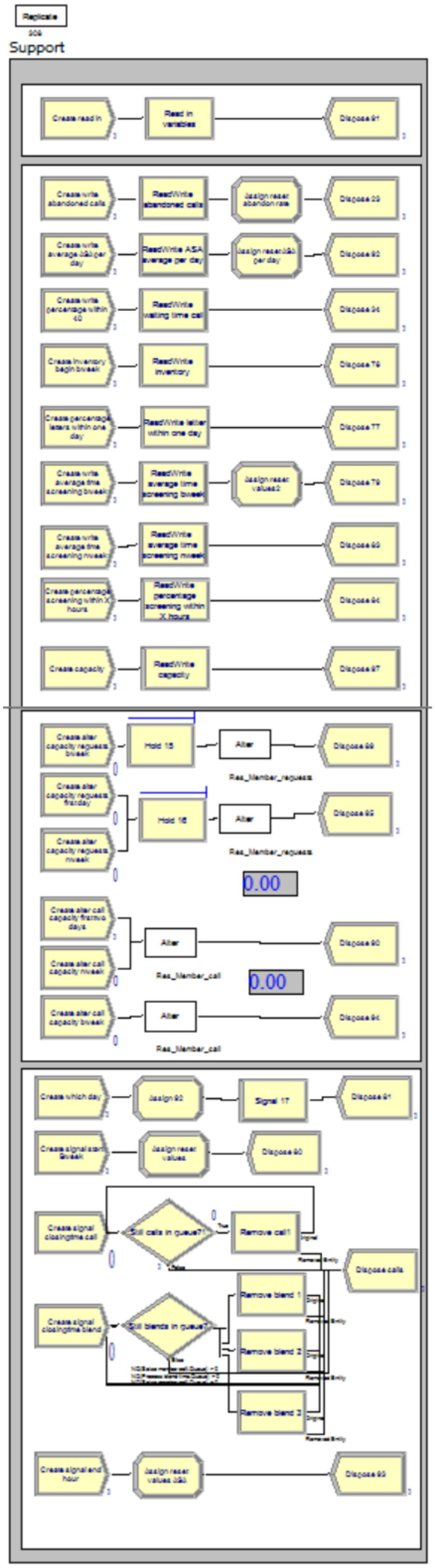


Figure F.6: Subsystem Support DDB

G | Interview summaries

To evaluate the decision aiding approach eleven interviews were conducted. This included interviews with the involved decision makers, involved analysts from the Operational Excellence Department and uninvolved analysts for the Operational Excellence Department who commonly do simulation studies. This appendix presents the summarised transcripts of the interviews, structured according to the interview structure from Appendix B. During the interviews questions were asked in order to identify the value of the decision aiding approach and to identify improvement possibilities. The interviews focused on four elements:

1. The strengths and weaknesses of the overall and specific parts of the decision aiding process
2. The increase in situation awareness
3. The strengths and weaknesses of the visualisation of the MOO results
4. The value of the decision aiding approach in an operational business context

This appendix is confidential