Flood protection policies in the city of Zutphen

Group 13: Dike ring 3

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Credits of the front page picture: [1].

TU Delft

Preface

This report is written for the course EPA1361, Model-based Decision-making given by Prof.Dr.Ir. Jan Kwakkel, Prof.mr.Dr. Hans de Bruijn, and Dr. Jazmin Zatarain Salazar. We want to thank the teaching staff for this complete, realistic, and challenging course. This course is built-up into two parts, a modeling part for policy advice, and political negotiation and decision-making part. Those parts will be separately documented in the rapport.

In the political part, a multi-actor decision-making game was played to simulate the decision-making in the room for the river project along the Ijssel river in the Netherlands. Every group of students was assigned to a specific actor to run analyses. This rapport is written as advice for the city of Zutphen. In this game, we had to negotiate with other actors to come up with a policy to avoid flooding in the Ijssel area.

To prepare for the debate, every group were assigned a set of analysts. For us, this was group 14. We want to thank them for the effort and the enjoyable teamwork we have done to achieve great negotiation success in the debates.

In our collaboration, we used a combined GitHub cloud to bundle our efforts and take a lead in the policy formation. Once the political negotiation part was finished we continued separately by running our analyses for the final report by making a fork of the shared GitHub on 04-06-2022. Due to the collaboration for more than half of the course, there could be some overlap in the code used for the rapport. All analyses, results, and conclusions could therefore be similar but were conducted separately.

Summary

This research employs a deep uncertainty model-driven approach using the EMA-workbench to support the municipality of Zutphen in creating a robust policy according to the Ijssel River flood management plan. The conducted analysis is not searching for an optimal solution, but to provide insights into the preferred policy for the main objectives of Zutphen:

- Safety: The 40,000 inhabitants of Zutphen should be well protected.
- A proper compensation in the case inhabitants have to be relocated is necessary.

This leads to logically wished policies that incorporate an increase in dike safety up to 1 flooding per 10.000 years is an important objective and in case of 'Room for River' (RfR) in Zutphen, the compensation should be higher than just the WOZ-value.

Considering Zutphen will have to make decisions under uncertainty, we first conducted an exploratory analysis to look for preferred policies in terms of *expected annual damage* and *expected number of deaths* for a number of scenarios. Then we optimized the amount of policies and verified the robustness. This resulted in a reduced amount of potential policies of 4 based on dike heightening, room for river projects, and an Early Warning System (EWS). These policies were found after generating over 250 scenarios. All of these results presented potential trade-offs.

The exploratory phase took off by performing an open exploration in which the trade-offs between the different outcomes of interest were assessed on an aggregate level by using extreme lever values. It turned out that in general, the higher the total costs of the project, and thus the more measures implemented, the lower the expected damage and number of deaths. Moreover, the policy that combined executing downstream RfR-projects and upstream dike heightening turned out to be the least uncertain.

Subsequently, it has been assessed which model uncertainties and levers cause the outcomes to vary the most. For this, a so-called SOBOL-analysis has been used. It turns out that both deaths and damages depend highly on the extent of dike heightening of dikes 1 and 3, and their probability of failure. Moreover, the amount of deaths is influenced highly by the (extent of) usage of an EWS. An important side note to these results is the fact that due to interactions between those parameters and others, lots of other pieces of information are to be taken into account as well.

After the SOBOL, PRIM-analysis has been performed where the *'Expected Number of Deaths'* for the whole region is set on an acceptable threshold and plotted in a coverage density trade-off graph. This led to 5 different dimensions of uncertainties, either pfails or DikeIncreases which have a significant influence on the expected number of deaths in the whole area. Results of the PRIM show still a broad spectrum of scenarios in which the expected number of deaths is low enough to meet the safety objective.

The dimensional stacking shows that a failure on dike ring 2, 3 or 5 would influence the number of deaths the most. Therefore, dike increases in these rings seem to be an important factor in keeping the number of deaths low. This is in line with the number of people living in those areas and the chance of dike failure. These insights are used in the robustness and optimization chapters.

The robustness analysis and optimization was performed using MORDM and MORO techniques. Both gave us an insight into different aspects of the problem and were useful. Both used thresholds (with a focus on minimizing expected deaths, especially in dike ring 3) in order to find an optimal policy combination, although said thresholds were applied differently. The results were similar, in that they showed that a mixed approach of combining Room for River and dike heightening policies was possible. However, the MORO technique showed the feasibility of not including Room for River policies if a combination of dike heightening policies and the Early Warning System was chosen instead.

Nonetheless, a combination of all three, namely Room for River, dike heightening and Early Warning System policies, is recommended as being politically most feasible. Specifically, the policy combination as found in MORO 0 is a good starting point for further analysis, as it scores well in terms of minimizing the expected number of deaths, especially in dike ring 3, while having acceptable total costs. Furthermore, it performed well in the robustness metrics and it agrees with the results found in MORDM, which also showed that a combination of available policies works best.

Contents

I

Part 1. Policy advise

1 Introduction

The Netherlands is one of the rare countries that have more than 50% of its surface below sea level [2] and that, consequently, has to adapt constantly to flood risk, especially with current climate change. In the summer of 2021, a large flooding occurred in Belgium, Germany, and the Dutch province of Limburg, where 240 persons lost their lives and which created up to 38 billion euros of material damage [3]. This was the first large flooding in the Netherlands since 1995 and put the subject of water management policies for rivers higher on the political agenda. In the past, most efforts were spent on raising the dikes to prevent flooding, but recently Rijkswaterstaat switched policies to the 'Room for River' (RfR) project that focuses on creating floodplains along rivers. The report of Klijn *et al.* (2013) identified up to 39 policies for the implementation of RfR depending on the wishes of citizens, and local and provincial governments [4].

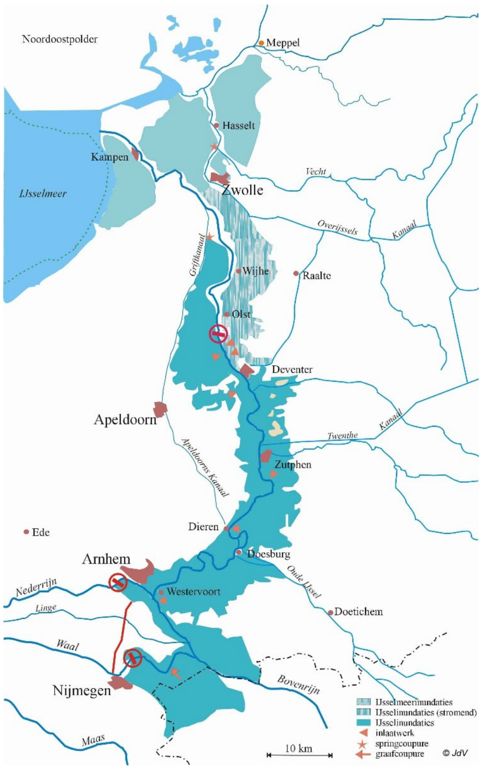
De Ijssel, an important river passing through the provinces of Gelderland and Overijssel, is aimed at implementing the RfR project (see Figure 1.1). However, several cities along the Ijssel, such as Zutphen, are not keen on giving land back to nature. Possible reasons for this are that floodplains (1) incur costs, for example in the form of compensation for displaced land users, (2) lead to loss of recreational nature, and (3) lead to a loss of potential construction areas for the current housing crisis in the Netherlands [5]. This leads to political complexities in the decisions making of RfR [6]. In the Zutphen area, the nature area Tickelbeekse Waard (Figure 1.1) is considered by Rijkswaterstaat as a potential location for RfR.

1.1. Objectives for the City of Zutphen

Increasing dike safety
For Zutphen, minimizing flood risk for the specific dike ring built along the city is crucial. At the moment, the dike ring is at the same level of protection as rural areas surrounding it. The city of Zutphen has over 40.000 inhabitants. For that, an increase in dike safety up to 1 flooding per 10.000 years is an important objective.

Compensation for relocation of inhabitants
If a policy requires the re-location of the inhabitants of Zutphen, They need to be well compensated. The current compensation rules in the Netherlands are based on an estimation called the WOZ (*Waarde Onroerende Zaken* in Dutch), this estimation is used for tax calculation. In case of relocation, inhabitants receive the WOZ value of their property, but moving costs and equity in the home are not compensated. For political gain, it is important to negotiate these extra compensations.

Other objectives
Other, but less important, objectives for Zutphen are conservation of natural areas like Tichelbeekse Waard, conservation of agricultural areas, and development of the Zutphen industrial harbor area. Also, the conservation of large housing building areas like *'Noorderhaven'* and *Park Helbergen* are important. These areas can be compensated by the province of Gelderland in case of RfR in these areas.



(a) Map of the Ijssel and cities it is passing [7]

(b) Location along the Ijssel which could be fit for RfR [8]

Figure 1.1: Overview of the Ijssel and the Room for River project

1.2. Research objectives

This report helps decision-makers in Zutphen to understand the current situation regarding possible flooding in the IJssel, what policy options are preferable, and how the political game around RfR at the Ijssel could be played. For that to answer, the following research question is necessary to answer:

What are preferred policies for Zutphen, within the project criteria, to decrease flood risk?

To achieve a robust flood policy for the next 200 years the following criteria will be taken into account: an amount of death below one person per thousand years, a total cost for dike increment of max 170 million euros, a total cost of RfR 1.95 billion euros, and a maximum evacuation cost of 1 million euro.

The report is constituted of two parts. First, policy advice for the city of Zutphen will be conducted. In a second part, a political review will be done on the decision-making process and the negotiations between the other dike ring in the province of Gelderland, the province of Overijssel (and its dike rings), and the Delta committee, and Rijkswaterstaat.

2

Problem Framing

2.1. Political framing for negotiation

The potential policy implementation of this system makes it deeply uncertain. The project consists of multi-actor policy development where each stakeholder has their agenda and specific knowledge. This makes the system a very interesting principal agent problem [9] analysis for Rijkswaterstaat. Consequently, the potential policy interventions space is very large. For a solution that fits every stakeholder, there needs to be a look for potential trade-offs not only for flood risk management, but also for land use and urban planning, economic growth, safety and livelihood of the residents, and costs of the project for every sub government included in the negotiations. In Part 2, the Political Reflection, wider stakeholder analysis will be given (see Figure 8.1). Although our role is to provide policy advice in the interest of Zutphen, it is very important to understand and acknowledge that "River and flood management of course requires an 'integral' or 'systems' perspective: policy analysts and policymakers should take the entire rivers and its functions into account, not just regional sections of the river or just the flood protection function" [6]. By solely chasing only Zutphen's needs (being safety by reinforcing dikes and an early warning system) there will be no possibility to meet the full requirement of the problem owner, Rijkswaterstaat. This problem owner seems to have a very large budget for flood prevention. Therefore, if there is a need for RfR in between the boundaries of the city of Zutphen, the report will aim to estimate the value of the nature area 'Tichelbeekse waard' so that it could be sold for high profitability to compensate citizens who are forced to move homes, and to have sufficient budget to develop the industrial port of Zutphen. More on this negotiations will be explained in the second part of the report. However, to reach the objectives from section 1.1, a policy consisting of dike heightening and an early warning systems, while avoiding the RfR projects, is the potentially most economic valuable policy for us. This is why 'Tichelbeekse waard' will play a key role in the negotiations.

This approach can lead to conflict with other stakeholders such as environmental groups, which have proposed RfR measures presented by Rijkswaterstaat to prevent flooding as well as to increase biodiversity, the breeding ground for birds, and other wildlife. Although we acknowledge that environmental concerns are an important part of the discussion of this project, they are not part of the main concerns of Zutphen in the development of the project because Zutphen has already a lot of natural areas surrounding. We also knew other actors had an environmental impact as their main concern.

2.2. Model framing and scoping

The problem follows the XLRM framework used by Grovers *et al.* (2015) [10], which is represented in Figure 2.1. In this Figure, X represents the external factors and uncertainties affecting the performance of the system when a policy has little or no effect anymore on the system. L represents the levers, these are the policies of the system and so the decision variables. R is the relation between the X and L, it is the calculation of the effect of policies by a certain X. This results in M, the performance metrics that indicated if the levers are functioning well.

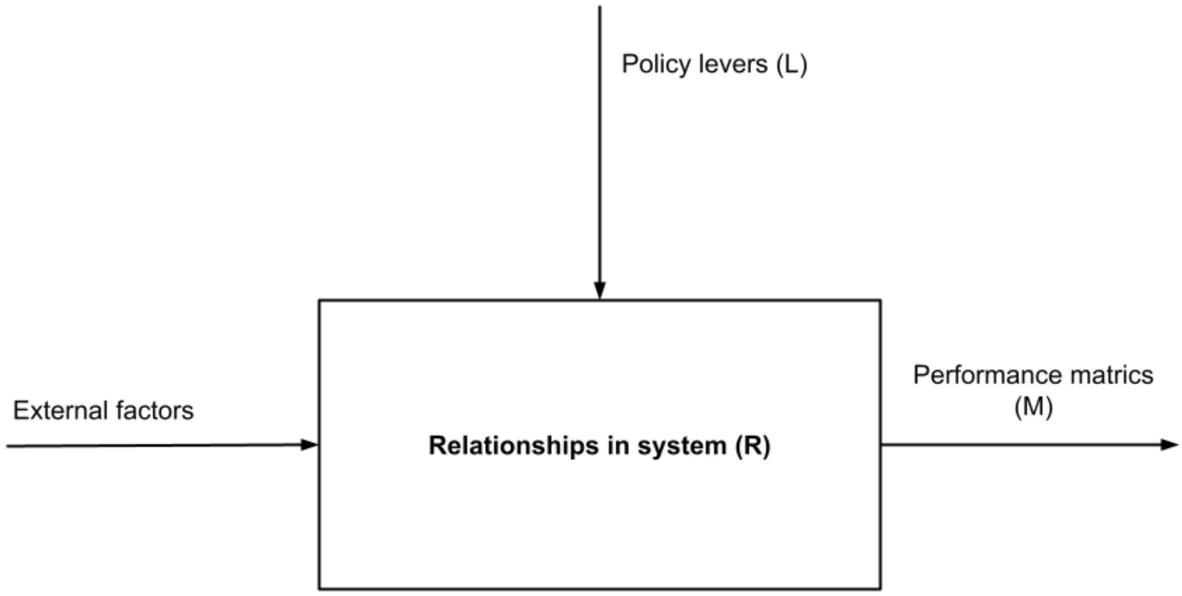


Figure 2.1: XLRM model

On the XLRM model, the simulation of the propagation of the flood throughout the Ijssel was analyzed using the Exploratory Modeling Workbench, a Python library that can be used to support decision-making under deep uncertainty [11]. The model, within the workbench, was used to assess the response of the dikes at each location in the Ijssel river basin and especially around Zutphen. The simulation gives insides on whether the dike will fail and the impact of it in time. The model calculates an estimation of *economic damage* and *number of deaths*. An important aspect of the model is that it is fit for making trade-offs between economic costs of the prevention and measures to reduce the risk of flooding.

To meet the political goals, it is key to find an agreement that on the one hand heightens the dikes of concern for Zutphen, and on the other hand is acceptable for other actors than Zutphen. This should be the main outcome of the discussion.

3

Approach

3.1. Open exploration using SOBOL and PRIM

3.1.1. General open exploration

The open exploration serves as the starting point for the exploration phase. Since the idea of this phase "is getting to understand when and how various sources of uncertainty negatively affect the performance of a candidate strategy" [12], and thus catching broad, aggregated signals of particular trade-offs within the model, problem formulation 2 of the *problem_formulation.py* file was used. Within this file, the following range of options as model input settings (levers) were available:

- *Dike Increase*: 0-10 dm for the 5 dike locations
- *RfR*: 0 or 1 for the 5 RfR locations
- *EWS_DaysToThreat*: 0-4 days

Since running the model with every possible set of combinations of these levers is both too time-consuming and not fit for visualization (and therefore drawing conclusions), 8 policies have been drawn up that cover the most important aggregated trade-offs of the model. To identify these policies, some combinations of extremes for lever values and some more in between-moderates have been used, as suggested by Lempert et al, 2006 [13]. The particular values used need some substantiation.

First of all, all policies will either take value 0 or 10 for the *Dike Increase* lever. After preliminary Excel calculations (see *Dijkkosten.xlsx*), the cost difference within heightening from 1 to 10 dm is relatively small. A couple dm more in height costs only a couple of millions more, on a total of over 100 mln. Euros.

Besides, the value for all, none or some (downstream/upstream) Room for the River (*RfR*) projects is either set 0 or 1, depending on the choice to execute these projects in rural or urban dike rings, and up- or downstream dike rings. Dike rings 1,2 and 3, all located in Gelderland, have been defined as upstream. The others, 4 and 5, are both located in Overijssel and will count as downstream dike rings.

Furthermore, the *EWS_DaysToThreat* lever is fixed at 3 days for all policies. The file '*EWS.xlsx* shows that an Early Warning of 3 days is as effective as one of 4 days in saving lives. Since the extra costs between 3 and 1 day (see *EWS.xlsx*) are negligible, 3 days are taken. Some preliminary simulation, with a small number of scenarios, has shown that usage of an EWS is not significantly driving up Total costs (see Appendix Figure 10.1). Due to time constraints, the analysis on this small number of scenarios is deemed suitable for the conclusion that the lever can be fixed at 3 days.

The policies are presented in Table 5.1. They were simulated over 1000 scenarios, differing in the values they were (randomly) assigned concerning the model's uncertainty inputs. This means 8000 experiments were conducted. Latin Hypercube Sampling was used as sampler when running the model. Latin Hypercube

Policies	Dike heightening Rural	Dike heightening Urban	RfR Rural	RfR Urban
1: No Action				
2: All	X	X	X	X
3: Rural RfR, Urban dike		X	X	
4: Urban rfR, Rural dike	X		X	
5: Upstream RfR, Downstream dike	X (Overijssel)	X (Overijssel)	X (Gelderland)	X (Gelderland)
6: Upstream dike, Downstream RfR	X (Gelderland)	X (Gelderland)	X (Overijssel)	X (Overijssel)
7: Only all RfR executed			X	X
8: Only all dikes heightened	X	X		

Table 3.1: Policy and scenario overview

Sampling needs less runs to reach representative distribution over the uncertainty space, since, "in contrast to simple random sampling, it simultaneously stratifies on all input dimensions" [14].

3.1.2. Using SOBOL uncertainty analysis

Now that, by means of open exploration, the relation between the different levers and outcomes have been explored on a quite aggregate scale, it is interesting to look at another driving force of model behavior: its uncertainties.

To assess which model uncertainties drive its behavior, a SOBOL analysis is performed for quite aggregated model outcomes and levers (*problem formulation 2*). Again, like in the open exploration, identifying global conclusions rather than specific levers/uncertainties to cope with are of importance in this phase of the analysis.

SOBOL analysis suits this purpose since it is a very robust [15], relatively accurate and user-friendly way of performing such a global sensitivity analysis [16]. SOBOL is used in many contexts to indicate to what extent the parameters of a model explain the variance of its KPIs, among others in complex system analysis [17] [18] [19] [20]. The method is relatively time-consuming. Therefore, the amount of experiments to be run is set as low as possible. To enable conclusions on the performed analysis, the model has to converge. Generally, this happens when the amount of runs is 1000(k + 2), in which k is the number of uncertainties of the model (which is 50) [16], in our case leading to 51.000 runs at least.

However, another important feature of the SOBOL analysis is the policy used for the analysis. When policy levers are expected to interact with the model uncertainties, specifying a policy is not necessary. In case of the dike model, it is probable that some levers of the model do indeed interact with the uncertainties. In the *funs_dikes.py-file*, it can be found that the chance of dike-failure is influenced by the dike height. Also, when a Room for the River project is executed, it leads to lower water level, leading to a lower critical water level, which also in that way decreases the dike failure chance.

Therefore, the policy did not have to be specified and all levers and uncertainties were collapsed into one single category (which was called uncertainties). It is apt to mention, though, that no interactions were directly found in the model for flood wave shape, breach width, its growth rate and the discount rate and those uncertainties are not expected to interact with the levers.

If interaction effects are taken into account and are to be examined, SOBOL requires twice the amount of runs it normally would require. Therefore, the model is run for 102.000 times in this analysis.

The outcomes to be assessed are the *Expected Annual Damages* and the *Expected Number of Deaths*.

3.1.3. Using PRIM analysis

When the uncertainties of interest will be clarified by the SOBOL, it must be indicated which uncertainty values possibly lead to required outcomes in line with the Dike rings preferences. For this, an oriented implementation of the patient rule induction method (PRIM) is used. The PRIM is a tool which is well-known in the field of decision-making under deep uncertainty [21]. It is often used to find a region of interest using a discrete sample. By using a set of hypercubes or boxes, it is defined in an interpretable way [22].

The PRIM is used to explore the range in which the uncertainties still meet an acceptable 'Expected Number of Deaths'. The maximum is set on 0.001 because this translates roughly in 1 in 100000 yearly chance of a dike breakage. A total of 25000 outcomes are generated using both 500 scenarios and 50 policies as inputs.

The box which is the most optimal choice is the best combination of both density and coverage. Coverage is the share of desired points in the box compared to the total number of desired points as outcomes, while the density tells us which percentage of the points in the box are desired points [23]. The standard settings are used for the *peel_alpha* in the PRIM. Furthermore, the threshold is 0.8 as learned in class to make sure the density is high enough in a box.

3.1.4. Using Dimensional Stacking

After the PRIM is performed we use the same created data to perform Dimensional Stacking (DS). DS involves two parts: identification of the most important uncertainties that affect the behavior of the system and creating a pivot table with the most important uncertainties. DS shows uncertain factors in order to reveal potential patterns in the values for single outcomes of interests [11]. The code uses random forest based feature scoring to identify the relevant uncertainty factors. In the analysis is worked with 2 numbers of levels and 3 bins. The number of levels influences the number of uncertainties included in the pivot table, which is in our case 4 uncertainties. The number of bins is used to make continuous uncertain factors concrete, in the case of 3 bins are the options 0,1 or 2.

3.2. Optimisation using MORDM and MORO

3.2.1. MORDM optimisation and robustness

After the open exploration has given insight into the model behavior, candidate policies have to be found. Optimisation techniques will search through this behavior to find optimal policies. An optimal policy can be seen as a policy that is not dominated by other policies. Therefore, multiple optimal policies will be found which all present a trade-off. Policies will be Pareto-optimal: it is not possible to find a policy which improves on one KPI without having worse results on another outcome.

Multi-Objective Robust Decision Making (MORDM) will be used to find these Pareto-optimal policies and search for robust solutions. MORDM is a technique to investigate multi-objective decision problems under deep uncertainty [24][23]. MORDM has 4 general steps [25]:

1. Problem formulation: The problem will be formulated from for instance the XLRM framework.
2. Generating candidate solutions: searching for the Pareto-optimal policies.
3. Trade-off analysis: Testing the candidate solutions under different scenarios. Certain solutions might be more vulnerable to deep-uncertainty than others. The robustness trade-offs will be tested under these scenarios.
4. Scenario discovery: Searching for the vulnerabilities of the candidate solutions. It will be investigated which (combination) of uncertainties leads to poor performance in the solutions.

It is important to know that the MORDM will find these robust solutions by using a reference scenario [25]. Therefore the results will be dependent on the reference scenario itself. First of all, the Pareto-optimal solutions will be found under the reference scenario. After the optimal solutions have been found, the optimal solutions will be tested under the uncertainties. Therefore MORDM assumes that the set of optimal solutions does not depend on the reference scenario [25].

During the robustness analysis, the candidate solutions will be evaluated by looking at two robustness metrics. The first metric entails looking at the deviation of results from the mean. This is done by looking at how much the results of a policy combination vary with different scenarios. The more constant the results are given varying scenarios, the more robust a policy combination is. The second metric is regret, where the results of a given policy combination are compared to the results of the most optimal solution for every scenario. The difference between these two is the regret.

The following settings have been used:

- Epsilon: The Epsilon value determines which policies can be considered as an optimal policy. A Epsilon value of 1 colloquially states that an improvement of 1, in for instance the costs, will be determined as a Pareto optimal policy. However, it will not be preferred to have a low Epsilon value. A low Epsilon value will mean that every small improvement will be seen as an optimal policy. Therefore a long list of policies will be generated which are all very similar. A high value of Epsilon will result in only one optimal policy which does not reflect any trade-offs that can be made.

  Therefore the Epsilon value is based on the range of the outcomes. An outcome with a high range will need a higher Epsilon. Therefore a small uncertainty analysis will be performed before the MORDM process starts. The uncertainty analysis will contain 1000 scenarios and 100 policies. Therefore an empirical indication of the range of every outcome will be found. The epsilon value will be 1/25th of this range. This results in a decent amount of optimal policies.

- Function evaluations: An amount of 75.000 function evaluations is used. The model clearly converges at this number of evaluations as will be seen in the results.
- Uncertainty sampling: Latin Hypercube Sampling (LHS) is used to select the scenarios during uncertainty sampling. LHS improves on random sampling and is a good method for selecting values of input variables [26].
- Problem formulation: Problem formulation 3 will be used for the MORDM analysis. This formulation provides a significant amount of information of both the outcomes for every dike ring and the total outcomes. This makes it possible to find policies which are both optimal for Zutphen and the other actors.

3.2.2. MORO optimisation and robustness

Besides MORDM, Many Objective Robust Optimisation (MORO) will also be applied. As already said, MORDM first optimizes for candidate solutions under a reference scenario, after which these candidate solutions are tested for robustness under uncertainty. MORO is very similar to MORDM, however MORO takes robustness into account directly. MORO optimizes for candidate solutions under a limited number of scenarios [27].

Therefore MORO does assume that the set of optimal solutions is independent of the reference scenario, which is a significant difference with MORDM. However, by optimizing over scenarios in the search phase, the candidate solutions might be less optimal under the reference scenario [27]. This could pose problems if there is a significant amount of evidence that the reference scenario is very likely to be the most probable scenario. However, MORO will probably find policies which are more robust than MORDM [27]. Furthermore, MORO will probably find a lower amount of optimal solutions. Additionally, MORO will have higher computational costs [27].

Last but not least, MORO will use the same steps as MORDM: Problem formulation, generating candidate solutions, trade-off analysis and scenario discovery. Because of their advantages and disadvantages, both MORO and MORDM will be used. Additionally, the results of these methods are compared. This will show further insights into both the case and the both techniques.The most important assumptions during the MORO analysis are listed below:

- Epsilon: For the MORO epsilon values, fractions of the maximum preferred KPI values were used. 1/10th, 1/25th and 1/100th were used iteratively, meaning for example that with a KPI of 0.05 preferred deaths at most, epsilons of 0.005, 0.002 and 0.0005 were attempted.
- Uncertainty sampling: Similarly to MORDM, Latin Hypercube Sampling will be used. Using LHS ensures the uncertainty space is fully covered while maintaining a bit of randomness.
- Number of scenarios: The number of scenarios is not predetermined. This value will depend on the convergence of the model. Ideally, the number of scenarios will be a bit higher than needed for convergence. Experimentally, we determined that 40 scenarios per policy is the minimum, while 80 to 100 would be ideal since it has almost fully converged without large fluctuations.
- Number of policies: A set of 50 random generated policies will be used to search for candidate solutions. These policies will be tested under all of the scenarios. The policies which are Pareto-optimal will be used in the robustness evaluation.
- Robustness KPIs: The A.3 Total Costs, A.3 Expected Number of Deaths and RfR Total Costs will be used to select optimal policies based on robustness. These are important outcomes for Zutphen.

3.3. Robustness evaluations

After finding potential policy combinations with both MORDM and MORO, it is necessary to ensure that these truly are viable. Up until now these policy combinations have been tested against a relatively small number of scenarios. This is fine when looking for potential choices, but when it comes to actually making a choice, it is necessary to ensure that it performs relatively well under many circumstances. This is called robustness. Checking the robustness of our potential choices will be done by using two different methods. The signal-to-noise ratio will be used to look at how the policy combinations perform under many different scenarios and how much this varies. The regret method will also be used, which will look at how far removed the policy combinations are for every given scenario from the optimal policy combination for said scenario. Analyzing these two metrics will give us good insight into the robustness of the potential policy combinations.

4
Open Exploration

4.1. Open policy exploration

4.1.1. Open exploration

For almost all the policy options, there turns out to be a positive correlation between the *Expected Annual Damage* and the *Expected number of deaths*. *The Total Costs* of taking no action in the model are 0. When comparing the *Total costs* with *Expected Annual Damage*, it is visible that there is a trade-off in costs over time. The outcomes with the lowest amount of expected damage do have higher *Total Costs*.

The *Expected number of deaths* compared to *Total Costs* show some interesting insights. No action gives the highest expected deaths but the lowest costs. Implementing all policy actions give a lower expected number of deaths but the highest costs. Better options considering the amount of deaths are the combination policies between RfR and dike heightening. For these options, the expected number of deaths are lower.

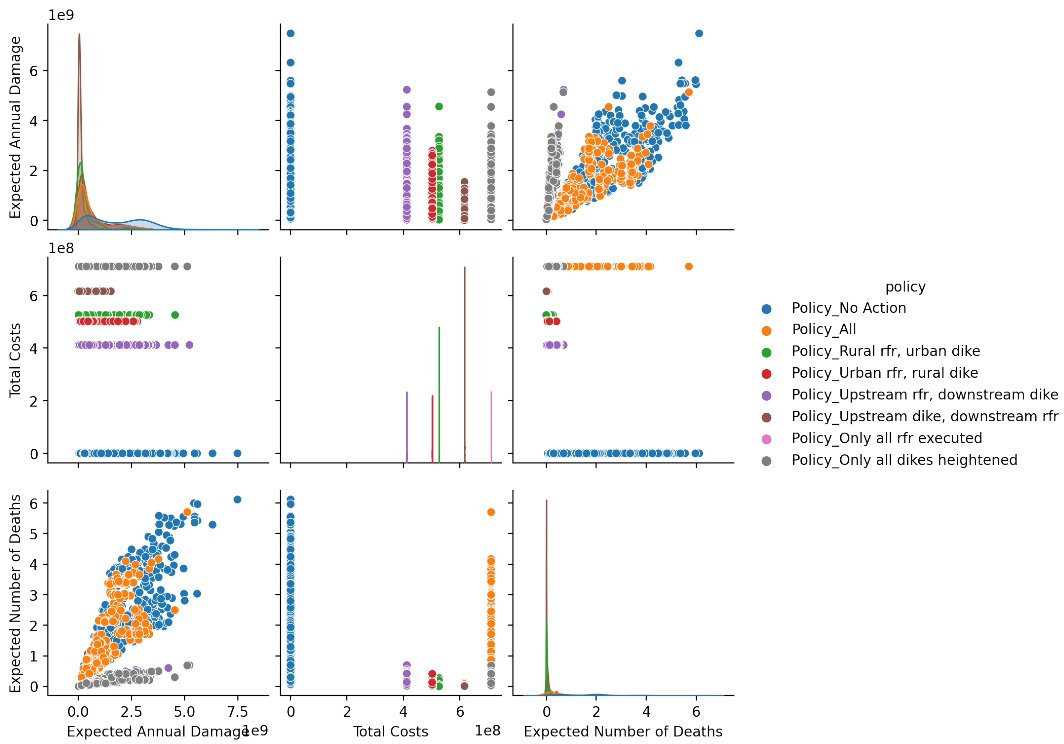


Figure 4.1: Pair-plot of the open exploration of the experiments and scenarios

All combinations of implementing measures lead to a clearly visible lowering of the expected deaths, and the effect of those on damages is also visible, however, the outcomes are more scattered here. The least scattered for both outcomes is policy 6, however, it comes with higher costs than policies 3 and 4 who also score quite well, though much less uncertain, on the outcomes of interest. The open exploration clarifies that the direction of the policies will be a trade-off between the total costs, and the damage and deaths that will be done. This insight is used in further analyses.

4.1.2. SOBOL analysis

Now that the relation between the different levers and outcomes have been explored on a quite aggregate scale, it is interesting to look at another driving force of the model behavior: its uncertainties.

First, some hypotheses are set out, so that our expectations can be assessed on whether they have been met by the results. For the amount of expected deaths and the damages:

- It is expected that the flood wave shape ID has no influence on the variance of its outcomes, since the height of a wave does not linearly go up with its ID, since the ID generates kinds of waves with different heights etc. randomly.
- It is expected that the breach width (Bmax) and its growth rate (Brate), and the discount rates do not influence the outcomes significantly. The reason for this is mentioned in the Open Exploration - Analyses section.
- All dike failure probabilities strongly influence their outcomes.
- The levers Dike Increase and all Room for River projects might to a high extent influence the outcome of the variables.
- EWS Days to Threat is of importance to only the amount of deaths, since material damage will be done anyways.
- Discount rates might be important for the net present value of the damage.

In Figure 4.2, the uncertainties and levers that influence variance of deaths for more than 5 percent according to the Sobol analysis are presented.

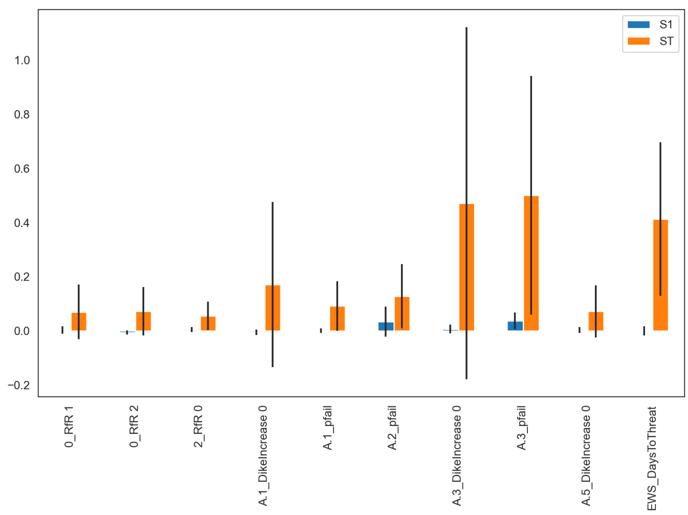


Figure 4.2: Sobol for first order (S1) and total order (ST) variance explanation of uncertainties on variable Expected Number of Deaths

As can be seen, not all hypotheses hold. It turns out that mainly dikes 1 and 3 are of important influence for the amount of deaths and damage. The other dikes appear to have a too low influence when either failure probability or their increase alter over the uncertainty-range. Furthermore, only 3 of the Room for the River projects influence the outcome variance for more than 5 percent, and not even much more, as can be perceived in the figure. The most influence can be perceived for the levers Dike Increase of dike 3, the Early warning, and the dike failure probability of dike 3. As can be seen, a lot of variance depends on interaction, since the first order variance does, for all levers and uncertainties, only make up a small part of the total variance. Therefore, in the Sobol *13.ipynb-file*, the interactions that influence the variance of the deaths-variable are depicted in a table (Cell output 14). It turns out that for our 3 largest influencing uncertainties/levers, the following interactions play a role in explaining variance (of mostly 5, sometimes 10 percent):

- With the Dike Increase of dike 1: the dike increases of other dikes, the failure, the Brates, Bmaxes, and the EWS-days, probability of all dikes, and also the discount rate amount. So, there are a lot of interactions, all with small contributions to the variance of the deaths-variable with Dike Increase 1.

- With the Dike Increase of dike 3, its interaction with pfail of dike 3 accounts for 17 percent.

- With the pfail of dike 3, its interactions with all Bmaxes, Brates and Dike Increases of the following dikes (4 and 5), their failure probabilities and the discount and EWS all add up about 10 percent for its influence on the deaths-variable.

This means that, however the variance within the deaths-variable results can be traced back to only a few levers and uncertainties, many more levers and uncertainties play a role within those influencing variables. Therefore, the influence of the variables mentioned as interactions above cannot be neglected in assessing what good policies for the deaths variable are.

In figure 4.3, the uncertainties and levers that influence variance of expected annual damages for more than 5 percent according to the SOBOL analysis are presented.

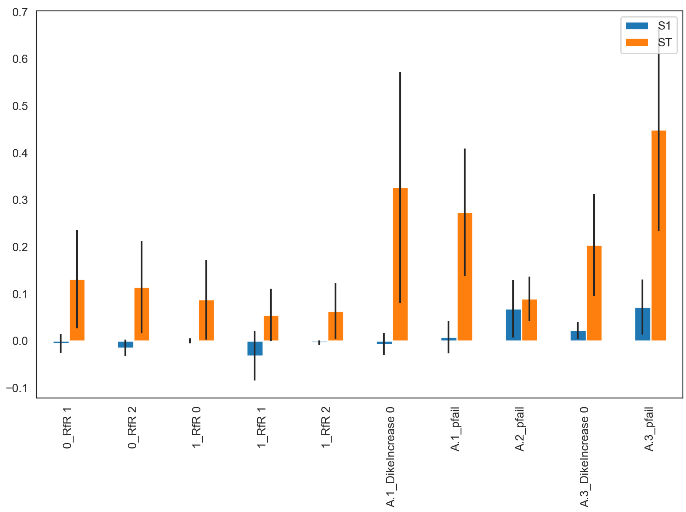


Figure 4.3: Sobol for first order (S1) and total order (ST) variance explanation of uncertainties on variable Expected Annual Damages

The interactions that influence the variance of the damages-variable according to the Sobol-analysis *G13.ipynb-file* are depicted in a table as well (Cell output 18). It turns out that for our 4 largest influencing uncertainties/levers, the following interactions play a role in explaining variance:

- With Dike Increase for dike 1, every uncertainty/lever except for the Room for the River projects, the Bmax and Brate and first-step Dike Increase of dike 1 all make up a slight interaction. The failure probability of dike 1 is a big interaction, with 24 percent.
- The pfail of dike 1 has interactions with all levers and uncertainties belonging to other dikes, of about 6-9 percent.
- The Dike Increase of dike 3 has one interaction that contributes for 24 percent to the damages variable, with the probability of failure for that dike.
- The failure probability of dike 3 has small interactions (+/- 5 percent) with all levers and uncertainties of dikes 4 and 5, the Days to threat and the discount rates.

To conclude, SOBOL-analysis has clarified that both the outcomes of expected damage and deaths are driven by the increase in dikes 1 and 3 and their probability of failure. Furthermore, the Early Warning System is of importance for the amount of deaths, but not for the damages, as was expected. Moreover, it has been found that many interactions, however small they might be, between other variables and the ones mentioned in this conclusion are present and of relevant influence. Consequently, they drive the outcome space of the outcomes of interest. Still, it is recommended to use the uncertainties and levers with the highest total order variance when assessing possible policies on their suitability, unless the presence of interaction effects is taken into account and mentioned.

4.1.3. Open Exploration approach: PRIM-analysis

In the first part of the PRIM-analysis, random policies have been generated. This results in a graph which shows the trade-off between density and coverage for the outcome *'Expected Number of Deaths'*. This outcome is set to be at max 0.001 per year. In the second part a specific box is explored via the inspect function and a scatterplot.

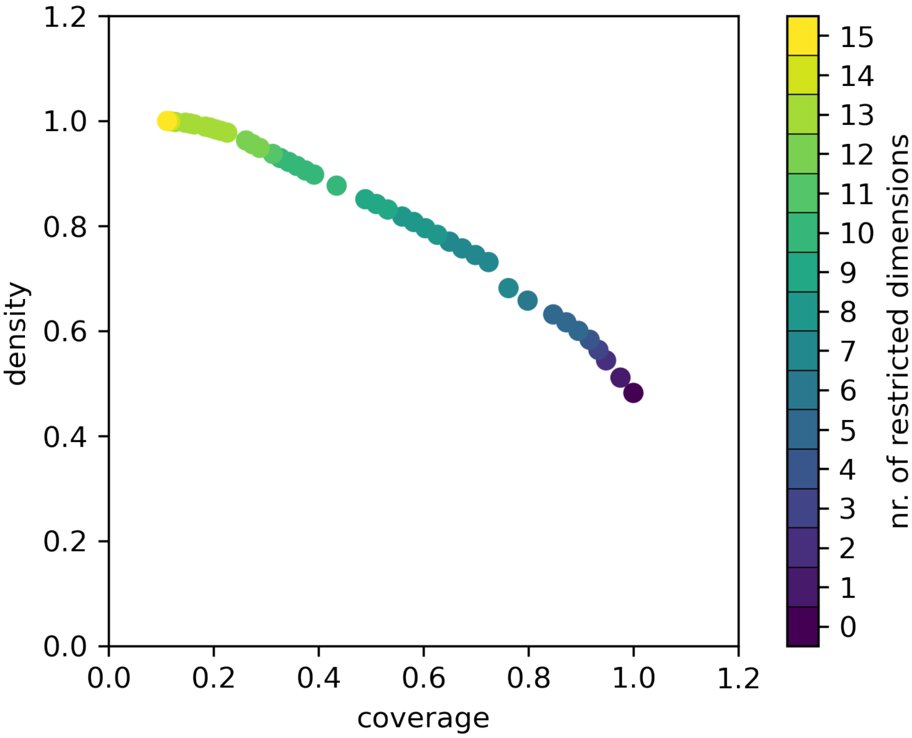


Figure 4.4: Coverage density tradeoff

In Figure 4.4 one can see that only the first 8 dots have a coverage of at least 0.8, the number which is usually aimed for. In this specific case, a coverage of 0,8 has a density of around 0,65, under five restricted dimensions, and can be found in box number 7. Box number 0 also exists, which makes box number 7 actually the 8th dot in the figure. This means that when more dimensions are included or when the density is increased that the coverage will no longer be above the 0.8 This is logical because adding a restricted dimension means an extra peel of data is done, which increases the density but decreases the coverage.

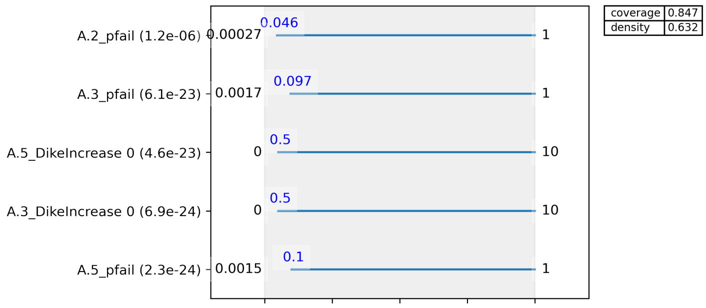


Figure 4.5: Range of the dimensions

The number of restricted dimensions indicates the number of restrictions on the uncertain input dimensions. The different ranges of the five dimensions used to peel the data are shown in figure y. These are in general still quite broad ranges because it is restricted only by one threshold, which is the *"Expected Number of Deaths"*. These ranges would decrease if more outcomes of the model are used to narrow the y variable. The uncertainties shown in Figure 4.5 all relate to DikeIncrease or pfail.

The scatterplot shown in Figure z shows the outcomes of the simulation score. The space within the red boxes indicates the partitioned space of the input values that will lead to a 0.8 coverage of the desired outputs, which are indicated with true in orange dots. All boxes fill quite a big percentage of the total partitioned space. This is in line with the broad range of the uncertainties as presented in Figure 4.6.

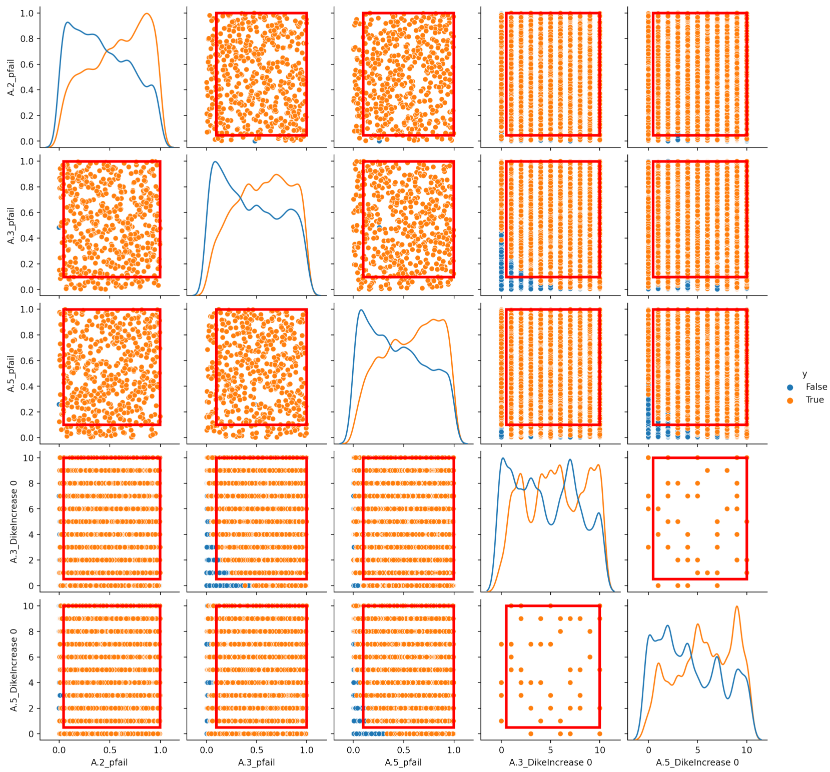


Figure 4.6: Scatterplot of the partitioned space of the input values

4.1.4. Dimensional stacking

Building further on the PRIM analysis, dimensional stacking is performed to show which uncertainties are most important that affect system behavior and create a pivot table using these uncertainties. Figure 4.7 shows that when all uncertainties are high, in general high concentrations of cases are present. A.5_pfail and A.2_DikeIncrease 0 both seem to have a high influence because the differences between the 0 and 2 bins are quite high in both cases. But the same effect seems to be the case for A.3_pfail.

The dimensional stacking shows that a failure on dike ring 2, 3 or 5 would influence the number of deaths the most. Therefore, dike increases in these rings seem to be an important factor in keeping the number of deaths low. This is in line with the number of people living in those areas.

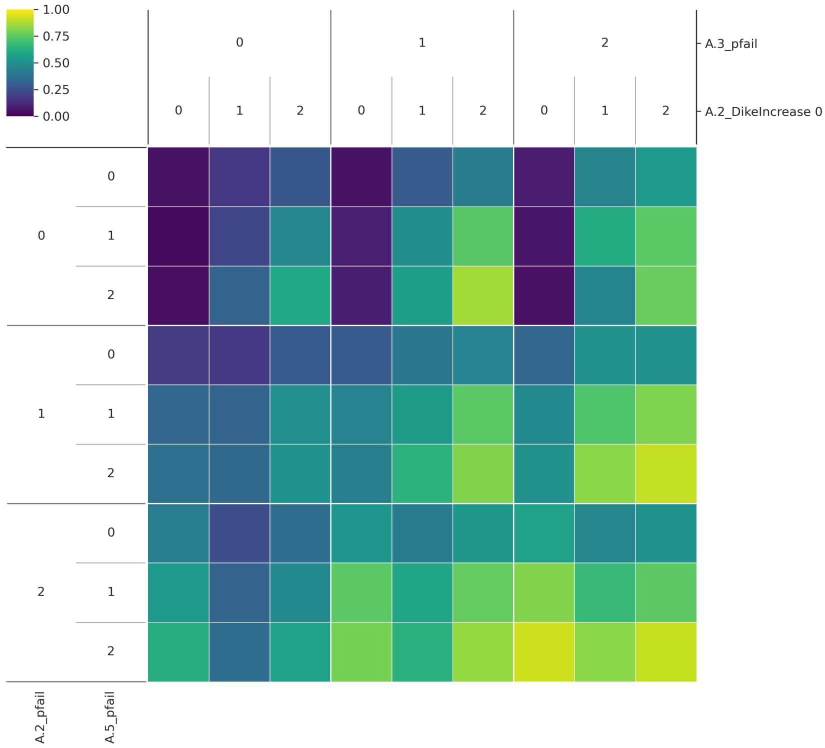


Figure 4.7: Dimensional stacking of maximum ‘Expected Number of Deaths’

5

Optimization & Robustness

5.1. MORDM

The results of the MORDM analysis are as follows. Firstly, figure 5.1 shows good convergence of the results of the optimization analysis, which themselves can be found in figure 5.2. Said figure shows a diverse range of optimal solutions, the number of which is 16.

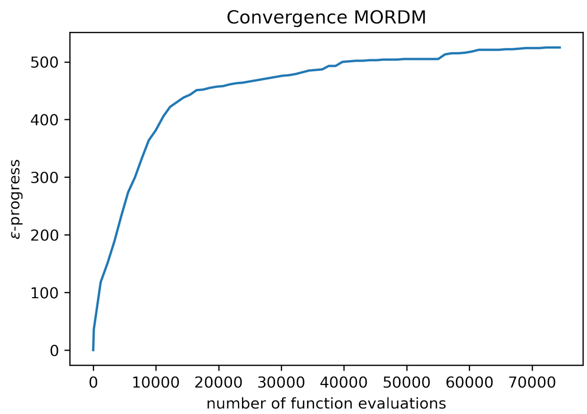


Figure 5.1: MORDM Convergence of optimized solutions

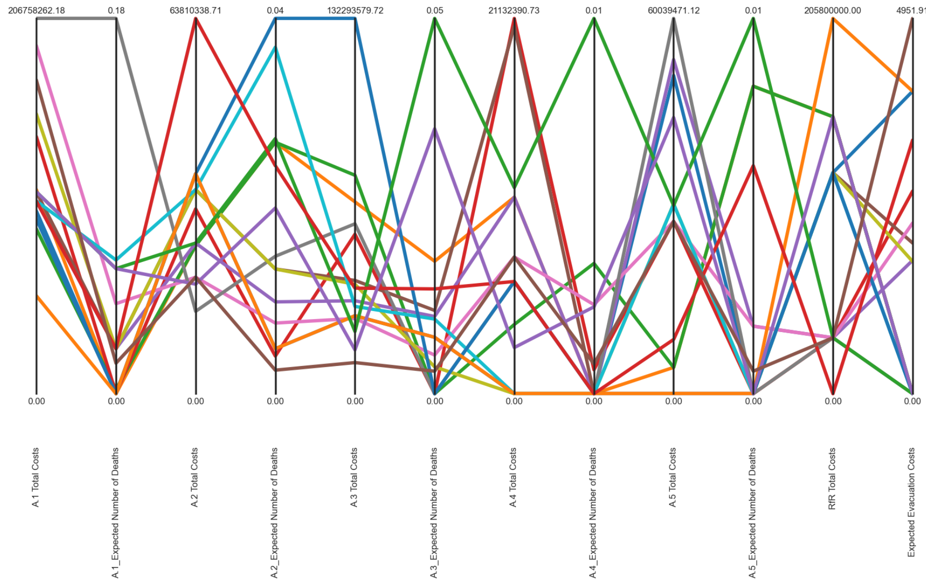


Figure 5.2: MORDM optimization results

From these, 4 solutions have been chosen for robustness analysis, which are policy combinations 2, 3, 7 and 10. They have been chosen as they satisfy the following criteria:

- Yearly deaths at our dike ring (A3) are at most 0.001 (Translates roughly 1 in 100.000 yearly chance of dike failure in A3 dike ring)
- Yearly deaths at all the other dike rings combined are at most 0.025 (Translates roughly 1 in 10:000 yearly chance of dike failure in other dike rings)
- Maximum costs at A3 are 170.000.000 (Our max preferred costs)
- Maximum Room for River costs are 1.950.000.000 (Rijkswaterstaat budget of 2.3 billion minus 350 million for our preferred compensation)

As can be seen, these criteria focus optimization for our dike ring, which is our mandate and thus our main concern. The question becomes if any of the policy combinations is both robust and politically agreeable with other parties. The policy combinations of each of these policies can be found in table 5.1.

	Policy 2	Policy 3	Policy 7	Policy 10
RfR Doesburg	0	0	0	0
RfR Cortenoever	0	0	0	0
RfR Zutphen	1	1	1	0
RfR Gorssel	1	0	0	1
RfR Deventer	0	0	0	0
EWS days to threat	0	3	0	0
Doesburg dike increase	5	7	0	4
Cortenoever dike increase	0	0	0	0
Zutphen dike increase	8	6	7	7
Gorssel dike increase	0	3	1	1
Deventer dike increase	0	2	3	0

Table 5.1: Policy and scenario overview

After having chosen the candidate solutions, their robustness can be analyzed. First, the 4 policy combinations are again simulated using 250 different scenarios. This provides the data necessary to see how said solutions perform in a wide range of possible scenarios, i.e. how robust they are.

The first robustness metric to be looked into is the signal-to-noise ratio. The higher the score the less the results vary with varying scenarios. The results of this analysis can be found in figure 5.3. The following can be seen. All of the solutions have very similar scores for the number of expected deaths in our dike ring, this being both a minimum and maximum of 0.00. Solution 3 has the lowest scores in terms of expected number of deaths and relatively high scores in terms of the total costs. Solution 7 has the highest score for both aspects of dike ring 1, with varying scores in other aspects.The other solutions score relatively low for dike ring 1 and vary in performance for other dike rings. Overall, another robustness metric is necessary to properly interpret these results.

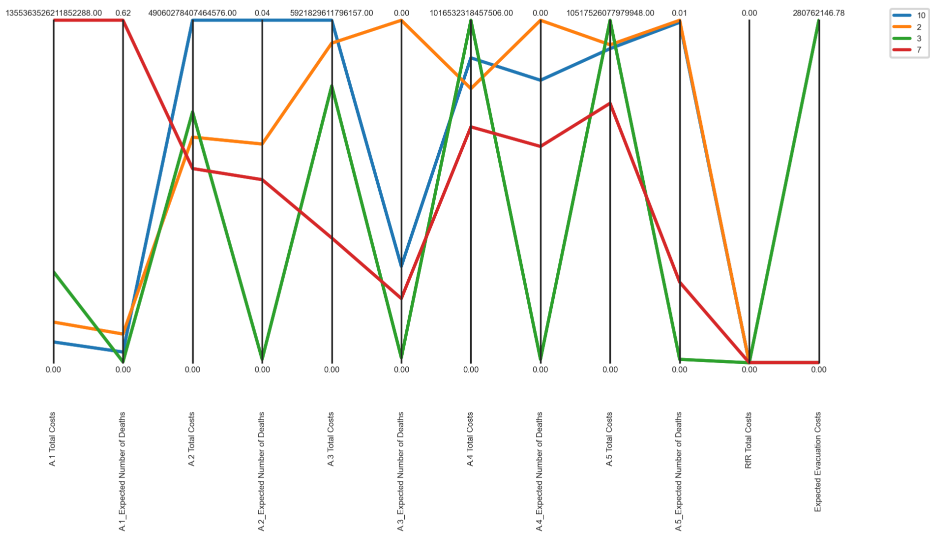


Figure 5.3: MORDM Signal to Noise results

The second robustness metric to be looked at is regret, which is the difference between the performance of a candidate solution compared to the most optimal solution for a given scenario. Figures 5.4 and 5.5 show the maximum regret per policy. A lower score is desirable. Solution 3 seems to be the winner when looking at the expected number of deaths, with the lowest maximum regret in terms of the expected number of deaths for all dike rings, and especially ours. It performs poorly in terms of maximum costs regret, but as safety is our priority this could be deemed acceptable. Solution 7 performs well in terms of costs, but extremely poorly in both aspects of dike ring 1 and poorly in terms of the total number of deaths. Solutions 2 and 10 perform poorly on average. Overall, solution 3 seems to be the most preferable one.

However, looking only at the maximum regret misses the whole picture. When looking at the spread of regret in figure 5.6, one can look at the chance of regret. Once again, a lower score is more desirable. As one can see, the expected regret scores are much better compared to the maximum regret scores, which oftentimes are outliers. All of the solutions perform extremely well in terms of the expected number of deaths in our dike ring, with figure 5.4 indeed showing the outliers. In terms of costs solutions 3 and 7 once again perform extremely well, with a single outlier in solution 3 accounting for its poor maximum regret score.

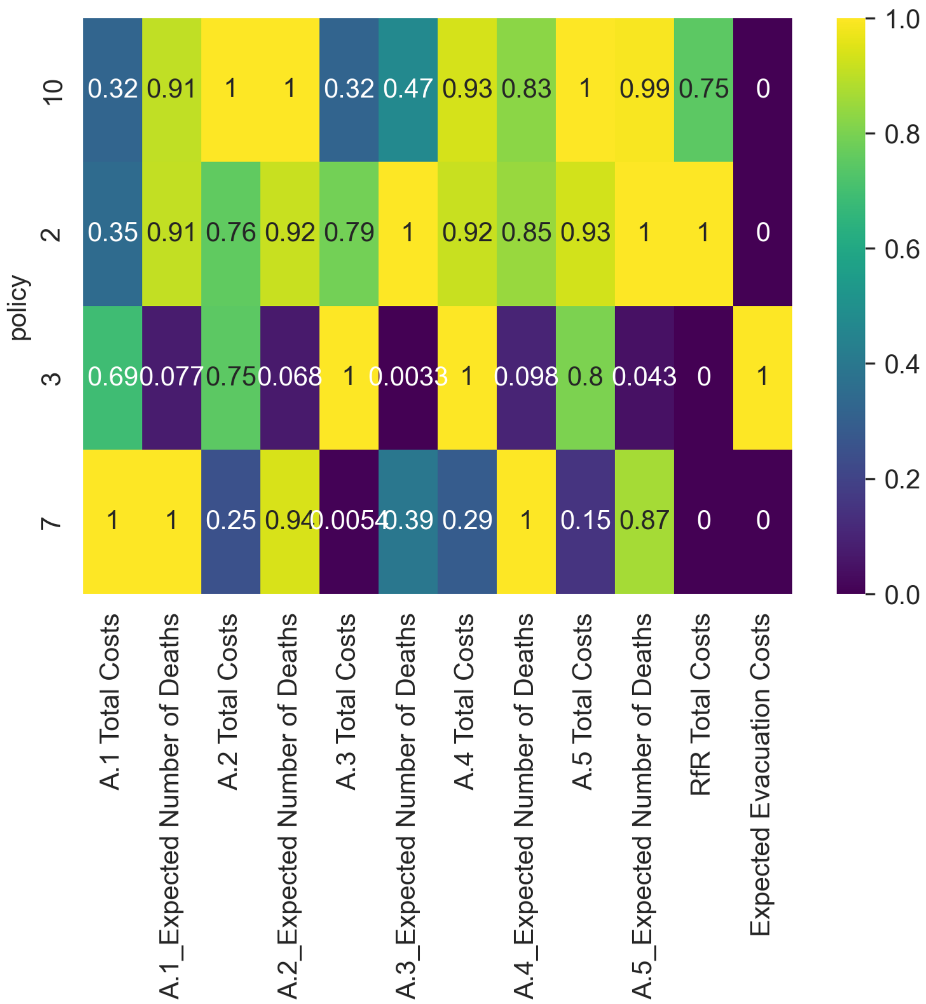


Figure 5.4: MORDM Maximum Regret table

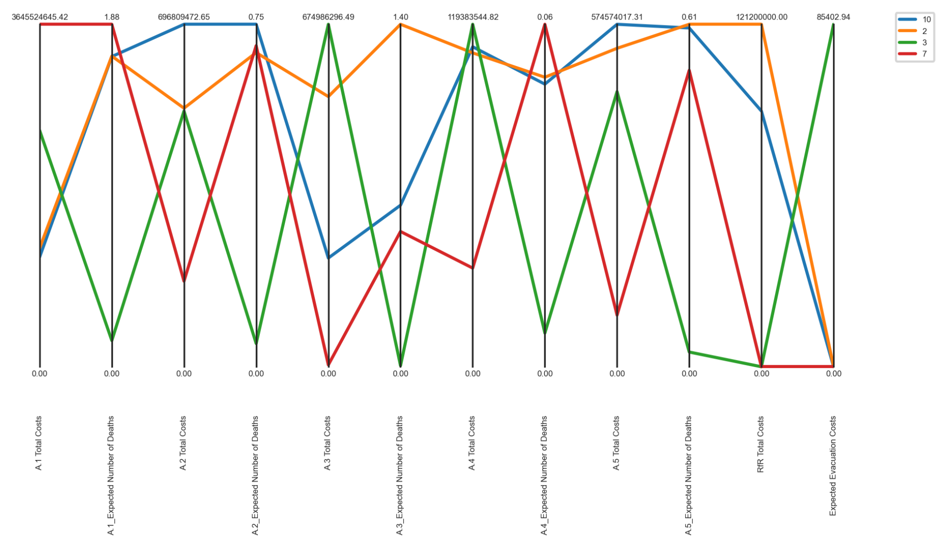


Figure 5.5: MORDM Maximum Regret graph

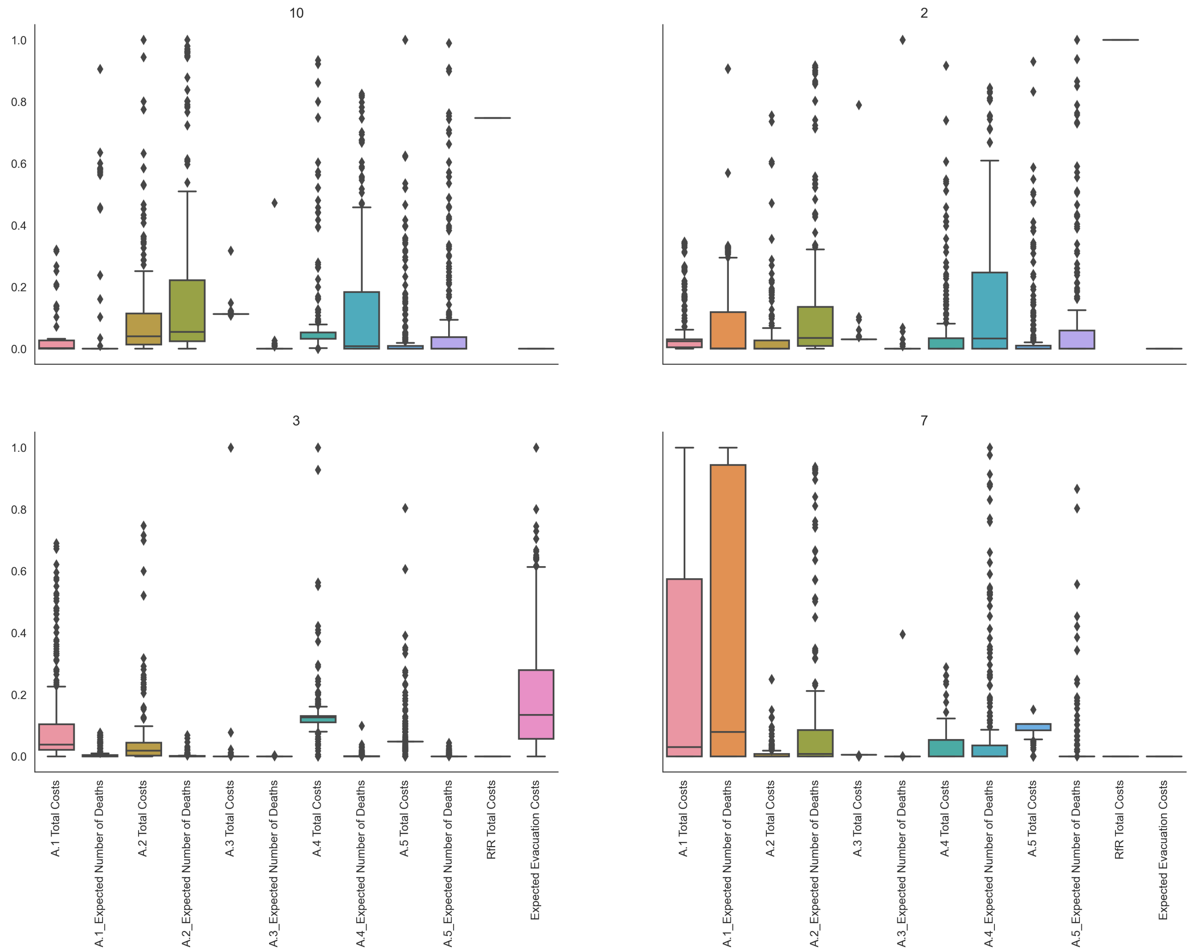


Figure 5.6: MORDM Maximum Regret boxplot

Looking at the two robustness metrics, one can conclude the following. Firstly, solution 3 should be chosen due to its very good regret performance, especially in terms of the expected number of deaths. This is despite the high total cost maximum regret scores, as looking at the box plot of the total cost regret scores shows that while the maximum regret is high, the expected regret is relatively low. Furthermore, it has an acceptable signal-to-noise performance. Solutions 2 and 10 also show acceptable performance, but are still inferior to solution 3, especially in terms of the expected number of deaths, which is our most important metric. Solution 7 is deemed infeasible due to the poor performance in terms of the number of deaths and total costs for dike ring 1. Looking into its policy combination, one can see that this is the only solution which does not increase dike height at dike ring 1. Looking at the policy combination of solution 3, one finds that a balanced approach of Room for River (especially at dike ring 3), dike heightening and an Early Warning System produces this desirable result, thus this is advised.

5.2. MORO

In this section the results of the Many-Objective Robust Optimization (MORO) method will be presented. First some intermediate results, such as the scenario convergence, will be shown, after which the robustness and actual values the three Key Performance Indicators (KPIs) will be reported for each different candidate policy.

All results presented are available in the MORO robust *optimization.ipynb* notebook.

5.2.1. Determining the number of scenarios for MORO optimization

An important step in the analysis is determining how much scenarios are enough to make the MORO search for robust policies effective. For this search, all KPIs have to be converged as much as possible, to have the least amount of stochastic variation for each candidate policy. With high convergence, the chance is smaller that a Pareto optimal policy will be labeled as not Pareto optimal or visa versa.

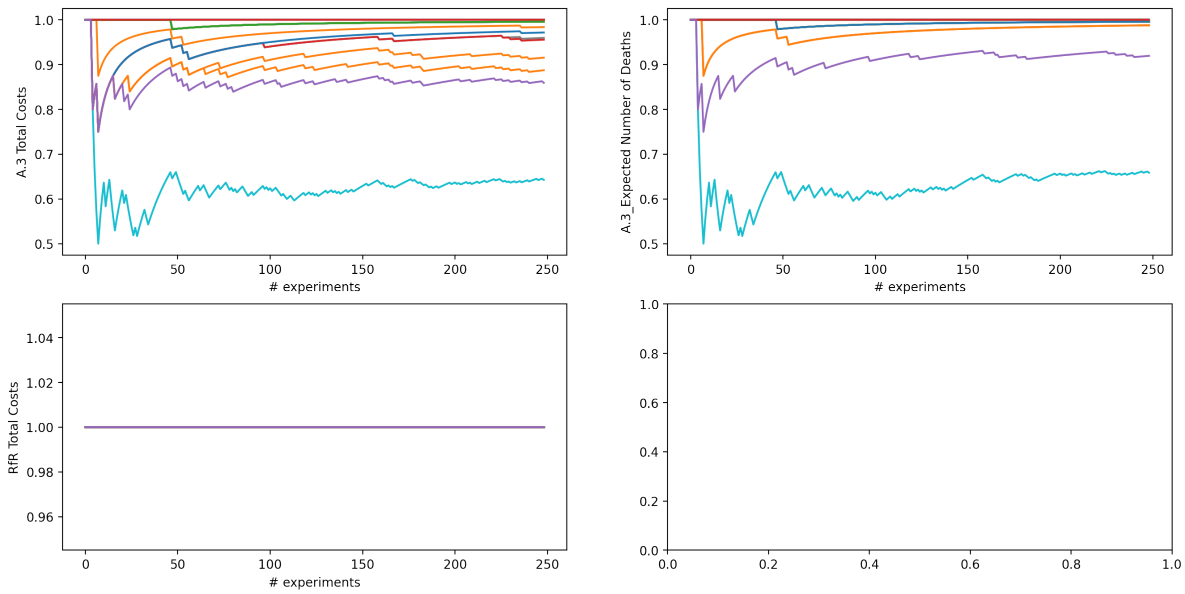


Figure 5.7: MORO convergence

From the 5.7 figure it can be determined that approximately 40 scenarios can be set as minimum to get the majority epsilon convergence for all three KPIs. When increasing the scenario to 80 or 100 a bit more convergence is reached, which could be used when enough computing resources are available. 40 scenarios is the value we used for the robust search, considering the limited computing resources available. When evaluating the found candidate policies, 1000 scenarios will be used for thorough evaluation.

5.2.2. Fine-tuning the preferred KPI values

Initially for each of the three KPIs a preferred maximum value was determined. However, after running a random set of policies and scenarios, the preferred KPI values could be further fine-tuned given in Table 5.2.

KPI	Max value (initial)	Max value (current)	Optimization direction
A.3 Total Costs	€ 170 million	€ 150 million	Minimize
A.3 Expected Number of Deaths	0.2 (0.001 per year)	0.05 (0.00025 per year)	Minimize
RfR Total Costs	€ 1950 million	€ 1700 million	Minimize

Table 5.2: KPI for MORO optimization

Based on this analysis of realistic cutoff values, we would like the number of deaths in the A.3 dike ring to decrease the most. We also would like a bit cheaper costs for ourselves, and think we can rally more support by other actors if the total costs decrease. This way we still cover the vast majority of the outcome space which should lead to robust policies.

	Moro 0	Moro 1	Moro 2	Moro 3
RfR Doesburg	1	0	0	1
RfR Cortenoever	0	0	0	0
RfR Zutphen	1	0	0	0
RfR Gorssel	0	0	0	0
RfR Deventer	0	0	0	0
EWS days to threat	1	2	0	0
Doesburg dike increase	9	6	9	6
Cortenoever dike increase	6	6	5	7
Zutphen dike increase	10	9	7	1
Gorssel dike increase	7	5	6	6
Deventer dike increase	4	4	7	6

Table 5.3: MORO Policy and scenario overview

From Table 5.3 all optimizations show that in Cortenoever, Gorssel and Deventer, no RfR should be implemented to come to a solution fit for Zutphen. Furthermore, they indicate that all dikes in the area should be hightened. The dike in Doesburg should be heightened with either 6 or 9 dm, in Cortenoever and Gorssel with 5-7 dm and in deventer with 4-7 dm. In Zutphen, the range is larger, spanning from 1-10 dm. Key choices are thus whether to implement RfR in Doesburg and/or Zutphen, to what extent to heighten the dike in Zutphen, and how many days to threat are to be used.

	Moro 0	Moro 1	Moro 2	Moro 3
Zutphen Total Costs	0.996	0.569	0.599	0.523
Zutphen Expected Deaths	1	0.999	0.605	0.441
Room for River Total Costs	1	1	1	1

Table 5.4: KPI robustness

Considering the KPIs, Moro 0 turns out to be very robust. This means that it is very likely that this policy Zutphen will reach its goals. For the other policies this is less certain, especially considering the total costs for Zutphen and its expected deaths. The table does merely indicate robustness and not that this is definitely the best policy.

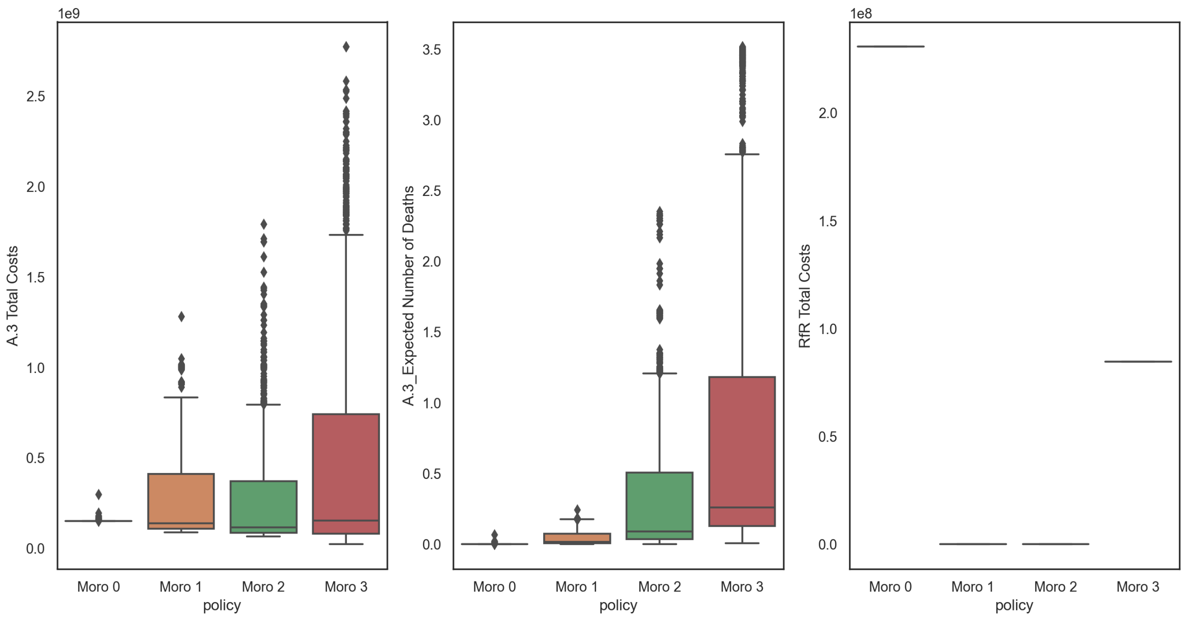


Figure 5.8: Box plot of KPI's from candidate policies

From Figure 5.8 can be seen that MORO 0 and MORO 1 are the two self generated policies that stays within the budget limits and have the lowest *amount of expected deaths*. Interesting is to see that the MORO 0 has a very low variation of costs because nearly any dike will be increased. All the cost for this policy are for the RfR.

MORO 1, despite a higher amount of death can also be interesting for Zutphen because of its absence of RfR, this is lowering the cost significantly. In this policy only dike increment is included. A disadvantage of MORO 1 is that it is not including biodiversity issues.

To gain political alias, Figures 5.9 and 5.10 dive deeper into the advantages for other dike rings.

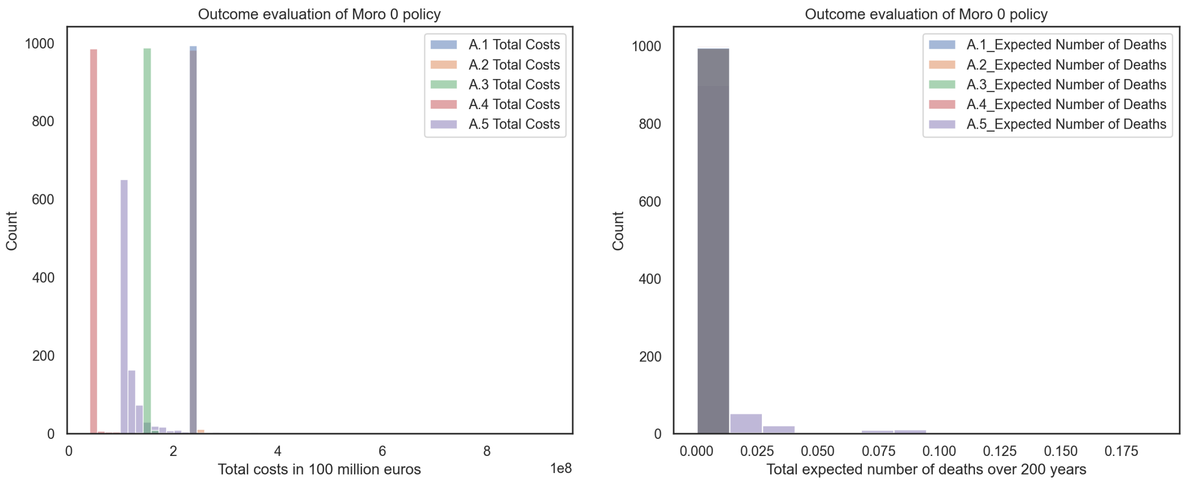


Figure 5.9: Outcome evaluation for candidate MORO 0

From Figure 5.9 can be seen that in nearly every scenario the total cost for dike ring 1, 3, and 4 are staying below 200 millions euros. These dike rings will be in favor of these policy. Dike ring 1 & 5 will have total cost over 200 million euros. For every scenario, for every dike ring the *total expected number of death* over 200 years will stay below the 0.1. This will be in line with the wishes of all dike rings.

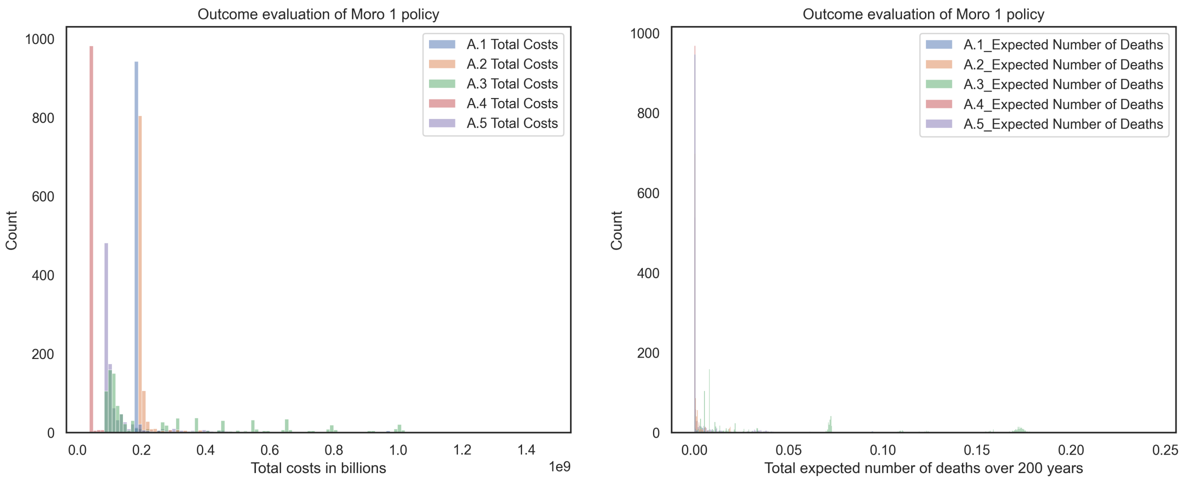


Figure 5.10: Outcome evaluation for candidate MORO 1

As conducted from Figure 5.8. The total cost of MORO 1 are higher. In Figure 5.10 this can be seen as well because the project cost could increase for dike ring 2 and 3, in some scenarios, over 200 million euros and could even reach the 1 billions euros. However, the total amount of deaths for every dike ring are lower the 0.1. This makes MORO 1 a safer policy combination.

6 Conclusion

6.1. Conclusion Open Exploration

In the open exploration, it was found out that a policy with dikes heightened upstream and RfR executed downstream was the least uncertain policy. Furthermore, the expected trade-off between deaths and damages on the one hand and the total costs of the whole project was confirmed. Furthermore, it has become clear by performing a SOBOL-analysis that the increase in dikes 1 and 3 and their probability of failure are driving both damages and deaths to vary. Moreover, the EWS is of importance for the amount of deaths, but not for the damages, as was expected. Last of all, the SOBOL-analysis has made clear that interaction effects between the most important drivers of uncertainties and other parameters are not to be neglected, but since the open exploration intends to yield a global overview, is eventually of minor importance. By means of PRIM- and Dimensional-Stacking-analysis, the conclusion is drawn that failure of dike ring 2,3 or 5 have the biggest influence on the number of deaths in the whole project. This means that Zutphen, as actor of dike ring 3, can make quite a good case to heighten their dike ring based on this outcome, which aligns to their goal.

6.2. Conclusion MORDM and MORO

The MORDM analysis has shown that a balanced combination of policies is key to a robust solution. Not heightening the dikes enough and not having an Early Warning System leads to a situation as seen with dike ring 1 in solution 7, where the expected regret in terms of expected number of deaths (i.e. the expectation of a dike ring flooding) is relatively high. Instead, heightening dikes, choosing even just one Room for River policy (like in solution 3, where only the Tichelbeekse Waard Room for River policy is chosen) and having an active Early Warning System provides very good performance in terms of minimizing the expected number of deaths while still performing adequately in terms of the total costs.

From the Multiple-Objective Robust Optimization (MORO) analysis we can conclude that there are multiple potential policies which prove, within the limits of our model, very robust for our preferred KPI limits. We found and investigated four policies. Especially the MORO 0 policy is only in a very select number of scenarios (4 out of 1000) not withing the limit of one single KPI, the A.3 costs, and performs perfect on all other KPIs and scenarios. Withing these KPI limits, it's not only very robust but also scores very well on the average and 95% values of our KPIs.

While falling fully within the KPI limit, MORO policy 0 has the highest Room for River costs. An alternative could be Moro policy 1, which has far lower costs, since no Room for River project have been implemented at all, relying fully on dike heightening and early warning systems. It has however higher costs and deaths for A.3

MORO policies 1 and 2 don't implement any Room for River project, while 0 and 3 do. While the former policies score consistently low on the costs and deaths metrics for the A.3 dike ring, they don't offer any additional room for nature. Thus it might be easier to get environmental groups behind policies 0 or 3.

Looking at other dike rings, the optimization process also attempted to lower their costs and deaths as much as possible. Therefore, the 200 year costs per dike ring don't increase above 250 million per dike ring, and the number of deaths stay well below even our own standards.

From this analysis, considering the limits of our model, we can conclude that the room for river project can be implemented successfully, reducing the flood risk significant, while being reasonable affordable, and proving new space for nature with some of the policies.

Overall, the policy combination as found in MORO 0 is a good starting point for further analysis, as it scores well in terms of minimizing the expected number of deaths, especially in dike ring 3, while having acceptable total costs. Furthermore it performed well in the robustness metrics and it agrees with the results found in MORDM, which also showed that a combination of available policies works best.

7 Discussion

First of all, this research is based on a single model of the room for river project. A model is a representation of the real world, and is by definition not perfect. Many assumptions, reductions and imperfections persist. Within reasonable limits, most of these were validated or sourced from expert opinion. While this research could provide valuable insight in the mechanics behind potential room for river policies, it has no predictive value at all.

A limited selection of KPIs has been used, to mainly focus on the priorities of the A.3 dike ring located in Zutphen. While costs and deaths were minimized for all KPIs, extensive robustness analysis and validation were only done for the three KPIs most relevant to the Zutphen dike ring. A larger set of KPIs could be used in future research to provide broader perspective and insights.

On an ethical perspective, it can be discussed whether the report approach to optimize solely the purposes of Zutphen. In line with Bentham (1890) [28], it is possible that a more utilitarian perspective on the problem would yield more optimal results for society/the region as a whole. However, it has to be recognized that this report serves the purpose of Zutphen. Further research could, however, take such an integrated perspective for the whole region into account.

From a general point of view on the model itself, a hard model limitation is the chosen time frame of 200 years, divided into 3 equal periods. While focusing on long term policy, this time frame is relatively arbitrarily, and should be varied with sensitivity analysis could be performed on it.

The models was also quite computationally intensive. Therefore a lot of time has been spent on running the different models. Not all every group member had a laptop to perform over 10.000 simulations, and large cloud instances were not always within budget. This was for example the case with dimensional stacking, MORO and MORDM. A whole weekend of effort could have been avoided by simply adapting the code in a way that 10000+ runs were not necessary. This is a valuable learning point for future studies.

Three major techniques were used in this research (Open exploration, MORDM, and MORO). Out of all those analyses, a range of potentially feasible policies has emerged. It would be interesting if the policies that emerged from the open exploration could be compared to the policies that emerged out of the robustness-analyses.

Diving in details of these analyses, the SOBOL results are to some extent hard to use for further analysis, mainly because it turned out that incorporating all levers and uncertainties into the analysis yielded lots of interactions that turned out to be of influence on the outcomes of interest. This huge complexity makes it difficult to find broad correlations and insights. A recommendation for further research is to make a clear distinction between which levers to incorporate into the analysis and which not, to reduce the model complexity.

One of the limitations of our performed analysis is the fact that the PRIM results are only tested on a maximum of the expected number of deaths and not on any other outcome of the model. This makes that the outcomes are still quite broad and don't really add the value you want from a PRIM analysis. The partitioned space of the input values in the scatter plot almost covered the whole outcome space in our analysis, a more narrowed down outcome here would be preferred. Another limitation might be the fact that the PRIM is performed in the exploratory phase. A PRIM analysis could benefit from an earlier performed SOBOL or MORDM to narrow down the candidate solutions more before conducting a PRIM. This would mean that the PRIM would be used to discover scenarios on the candidate solutions rather than purely exploratory.

The MORDM model showed to be very sensitive to the Epsilon values. Slightly smaller Epsilon values could result in a significantly higher number of optimal-policies or even a non-converging model. Therefore, our analyses are largely dependent on these Epsilon-values. Future research could search for the influence of Epsilon-values on the conclusion that will be drawn.

The robustness analysis gave us key insights into preferred policy combinations. However, there were still some improvements possible in our robustness methodology. These include using more robustness metrics, making a broader selection of scenarios with multi-scenario MORDM and performing a more detailed analysis of the results. Nonetheless, given the time and resources available to us, the robustness analysis performed is deemed to be sufficient.

II

Part 2. Political Reflection

8

Negotiations for Room for River in the Ijssel area

8.1. Introduction

This chapter will reflect on the political process during the debates. It will mainly explain the process of what happened with our advice between the initial conversations until the final debate. First of all a small recap will be given of the goals of Zutphen. Second, the political environment will be drawn and how this environment leads to tensions with our advice. After that, our strategy to handle these tensions will be outlined and how it evolved over time. Last but not least, there will be a reflection on the whole process and how it could be improved.

8.2. Objectives

The objectives which can be found in paragraph 1.1 can be summarized as follows:

- Safety is our most important concern. The 40,000 inhabitants of Zutphen should be well protected. For that an increase in dike safety up to 1 flooding per 10.000 years is an important objective.
- A proper compensation in the case inhabitants have to be relocated is necessary. In case 'Room for River' (RfR) is implemented, the compensation should be higher than just the WOZ-value.

Our role as representatives (but also as analysts) of Zutphen is to make sure the interests of Zutphen are considered in the decision-making. Our advice is misused when other parties choose to neglect our interests in their own favor.

From the situation of Zutphen, dike heightening would be the preferred option. This option saves the most lives in the neighborhood and has the lowest costs. However, before all negotiations started, there were already some tensions that we expected.

8.3. Political Environment and tensions

Figure 8.1 shows the actors which were present in the situation and their role:

The flooding problem of the river IJssel is ill-formulated and the information is often confusing and contradictory. There is no single solution that can be solved by optimizing for a single criterium. Therefore the problem can be seen as a 'wicked problem' [30].

First of all, we expected a tension between the urban areas (Zutphen and Deventer), and the rural areas (Doesburg, Cortenoever, and Gorssel). The urban areas are mainly concerned about the safety in their densely

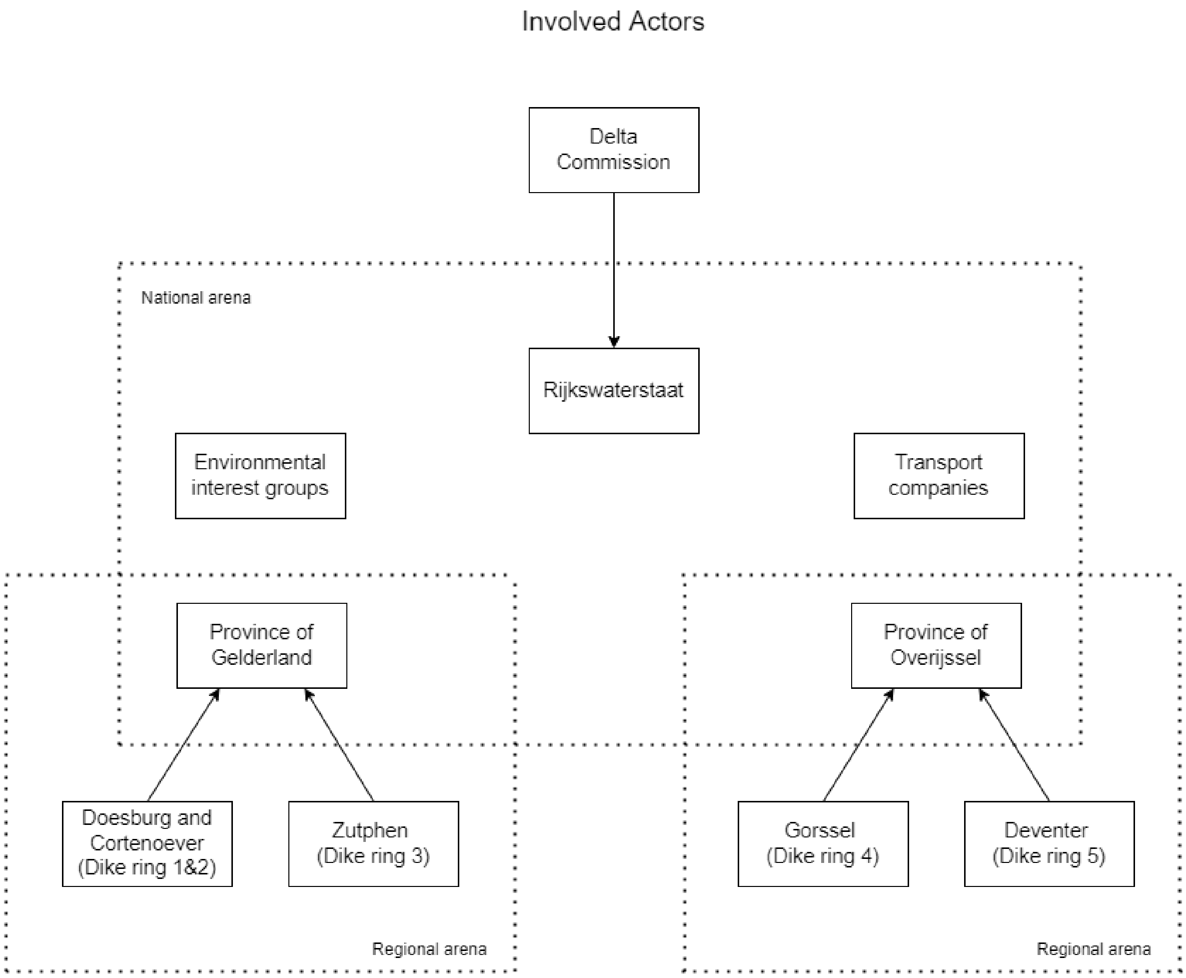


Figure 8.1: Actors involved in the political arenas [29]

populated areas. The rural areas however, were expected to be more concerned with the business case of the agricultural companies. Dike heightening in Zutphen would possibly lead to RfR in the rural areas. Therefore it was estimated that there would be a clash between the values based on the economy and safety.

Furthermore, there was an expectation that there would be a tension between upstream (Gelderland) and downstream (Overijssel). Policies implemented in Gelderland will probably affect the situation in Overijssel. For instance, raising the dikes upstream improves the flood protection upstream, but will lead to a higher peak-discharge downstream. Additionally, RfR projects upstream will cost land, but will lower the chance of flooding downstream [31]. The asymmetry that downstream depends on upstream and not vice-versa will lead to tensions [32].

Last but not least, tension between the Transport companies and the Environmental interest groups was expected. However, it was not yet known what their response would be to dike heightening in Zutphen. This would be dependent on whether the Transport companies would focus more on transportation over land versus transportation over water. Furthermore it was still unclear how the environment would be impacted by raising the dikes.

Due to the different political arenas from Figure 8.1 [29] there is also a high interdependence between the provincial actors. Every Dike ring represented by their respective province during the national debates. So a high level of agreement between the dike rings will be necessary to avoid non representation by the province.

Because there are so many conflicting interests, we expected that the discussion would become political. Science can become a source of legitimate and relevant facts that are used by contesting parties. Therefore every actor will probably use the complex issue and its deep uncertainty to their advantage [33].

8.4. Strategy

As we already have seen, it is likely that some conflicts will occur during the debates. Furthermore, actors will probably use competing facts to legitimize their claims. To defend the case of Zutphen we have come up with three main strategies:

1. Make proper use of our assistant-analysts of Zutphen. These assistant-analysts were tasked with analyzing which policies would be optimal and how these policies would affect other actors. Furthermore their task was to create additional policies which would be optimal for other actors, but had potential negative effects for Zutphen. This resulted in a list of policies in which Zutphen could try to make alliances to avoid the negative effects.

   Our analysts from Group 14 performed this role well. They integrated themselves into the policy making process itself without becoming politicized. Furthermore their analyses were adaptive to the changing circumstances in the negotiations. They presented themselves as true policy brokers [34].

   Therefore we are thankful to our assistant-analysts .

2. Contact every actor: we should make sure that every actor knows the demands and situation of Zutphen. Even actors outside of Gelderland should be familiar with our interests.

   This is mainly achieved by making sure that meetings are organized according to a proper schedule. In total there were meetings with Doesburg & Cortenoever, Province of Gelderland, Rijkswaterstaat, Delta Commission and Deventer. Deventer was especially interesting as it is urban as well, but could receive disadvantages because it is more downstream.

   We have carefully prepared these meetings in order to prevent a clash. For instance: we could have framed the representatives from Gorssel as 'a horde of unorganized farmers'. However they would probably have reacted by a powerful victim-villain-hero frame: 'We, proud farmers of Gorssel, are threatened by the over-confident cities who think they can transfer their flooding problems to us. The Delta-Commission is the only partner which ensures that there is an actual integral solution which benefits all actors.' [35]

3. Improve the negotiation position: the leverage of Zutphen should be improved by a few tactics. These make sure the interests of Zutphen are better protected.

   The negotiation position is mainly improved by adding 'proxy' objectives. These are superficial objectives which could be used in the negotiations. During stiff negotiations concessions can be made on the proxy objectives without having to compromise on the actual objectives. Furthermore they create a multi-issue game which grants more flexibility in the negotiations [36].

   The following objectives have been added:

   - New commercial and recreational port: The province of Zutphen acts like it wants to build a new port. This port could help to transport agriculture products by the Transport companies. This project can only happen if RfR does not take place in Zutphen. This showed to be a very powerful objective throughout the debate.
   - Housing construction: In order to solve the housing crises in the neighborhood, an apparent housing development project is taking place. If the construction area will be used for RfR, the city of Zutphen will have to start a new project in order to solve the crisis. Therefore extra compensation is needed.

Before the first debate, there was a confirmation that the Transport companies were only interested in transportation by boats. Therefore the importance of the new port was stressed.

During the first preliminary debate, our group had an information advantage over the other groups primarily because we were one of the few groups who actually got results out of the model. The model indicated that raising the dikes was the best solution for Zutphen. Luckily, Doesburg & Cortenoever agreed on this fact. Furthermore, the Transport companies were very content with the plans of a new harbor. Additionally, we were able to convince the other groups that RfR at Zutphen (Thickelbeekse waard, Figure 1.1a) would cost €350million instead of the real €170million (the difference between the cost of dike heightening and the RfR project). However, the province of Gelderland sadly, did not want to discuss the plans. Instead Gelderland was more focussed on *'adaptive dynamic'* policies and collaborating with North Rhine-Westphalia.

The province probably aimed at adding resilience in the system by adding the *'adaptive dynamic'* policies. Although resilience is often more effective under uncertainty [6], resilience can also lead to problems. For instance, a the city of Deventer could receive 'resilient' protection by RfR in Cortenoever, however Cortenoever will have to give up land. Cortenoever will probably not agree on the fact that they should bear the costs for the protection of Deventer [6].
Although Cortenoever has different interests than Zutphen, we positioned ourselves by giving the confidence to Cortenoever that Zutphen would protect them. This created an alliance which we could use and probably abuse.

Sadly the talks about *'adaptive dynamic'* policies continued throughout the first real debate. The only points that came across were that Zutphen was going to build a new port and that the costs of RfR would be €350million. The province was not able to convince other groups that Zutphen wanted to raise their dikes. This was mainly because the first real debate was mainly focussed on *'adaptive dynamic'* etc. policies and not on actual content. But with the 350 million euros for RfR at Thickelbeekse waard we should have enough money to compensate citizens, heightening our own dikes, and expend our industrial port. This is still a good result from the negotiations.

For the last debate our advantage in information was used as well. The conclusions of the model were sent to Rijkswaterstaat so they could take the interests of Zutphen into account. The result of this was clearly visible in the debate. All of our demands were taken care of. Furthermore the last debate still continued the talk about our supposedly new harbor. All of this made it clear that the position of Zutphen was well considered.

8.5. Reflection

Based on the results we can see that the other actors and especially Rijkswaterstaat clearly were taking the interests of Zutphen into account. The dikes were raised for maximum safety and ultimately no compensation was needed. This was the result of strategies which turned out well.

Especially the tactic of improving the negotiation position of Zutphen showed its benefits. The idea of a new harbor was continuously part of the discussion. The fact that the other groups were not picking up on the new housing project does not raise any regret. It was already counted in that only the ideas which were raising the interest of other actors should be continued. Furthermore none of the groups were able to detect that the RfR at Zutphen would actually cost €170million instead of €350million. The strategy of contacting each actor has barely measurable results. The only real measurable advantage it had, was the fact that new ideas for Zutphen's negotiation position could be tested, without seeming contradictory with prior demands.

One of the risks with our strategies is that other actors might be able to detect them. Zutphen would not sound like a reliable negotiation partner if one of the actors would find that the RfR in Zutphen actually costs €170 million. Furthermore we would be inconsistent if other parties find that the interests of Zutphen are continuously changed (ie. harbor). We had some luck that this played out well for us, but we also had the risk of having a counterproductive strategy.

Another risk lies in the fact that we were potentially over-using our information advantage. Other actors might become cautious about the 'tricks' we might employ. This could make the other actors more hesitant to cooperate with us than they actually should be. The other actors could use arguments such as: 'the data is disputable', 'the methods are not suited', 'the scoping is debatable' [37]

The last risk lies in the fact that we contacted every actor. Instead of focussing on the most important actors in the process we spread our chances but also spend a lot of time on pre-talks. This may 'eat away' time that we could also spend on contacting actors such as Rijkswaterstaat and Gelderland. There was the risk that Rijkswaterstaat and Gelderland would neglect the interests of Zutphen, just because they had more close contacts with other actors.

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9

Appendix A: Code

In short, I expect at least the following: 1. A structuring of the policy problem 2. A well-argued selection of analysis steps, grounded in literature 3. Clear communication of results and their meaning within the policy context 4. Explicit policy advice, for a self-chosen actor within the context of the case study (see debate instructions for the actor constellation) 5. All code and data as appendix (maybe a link to a repository on github or a zipfile shared using a file transfer service).

10
Appendix B: Additional Figures

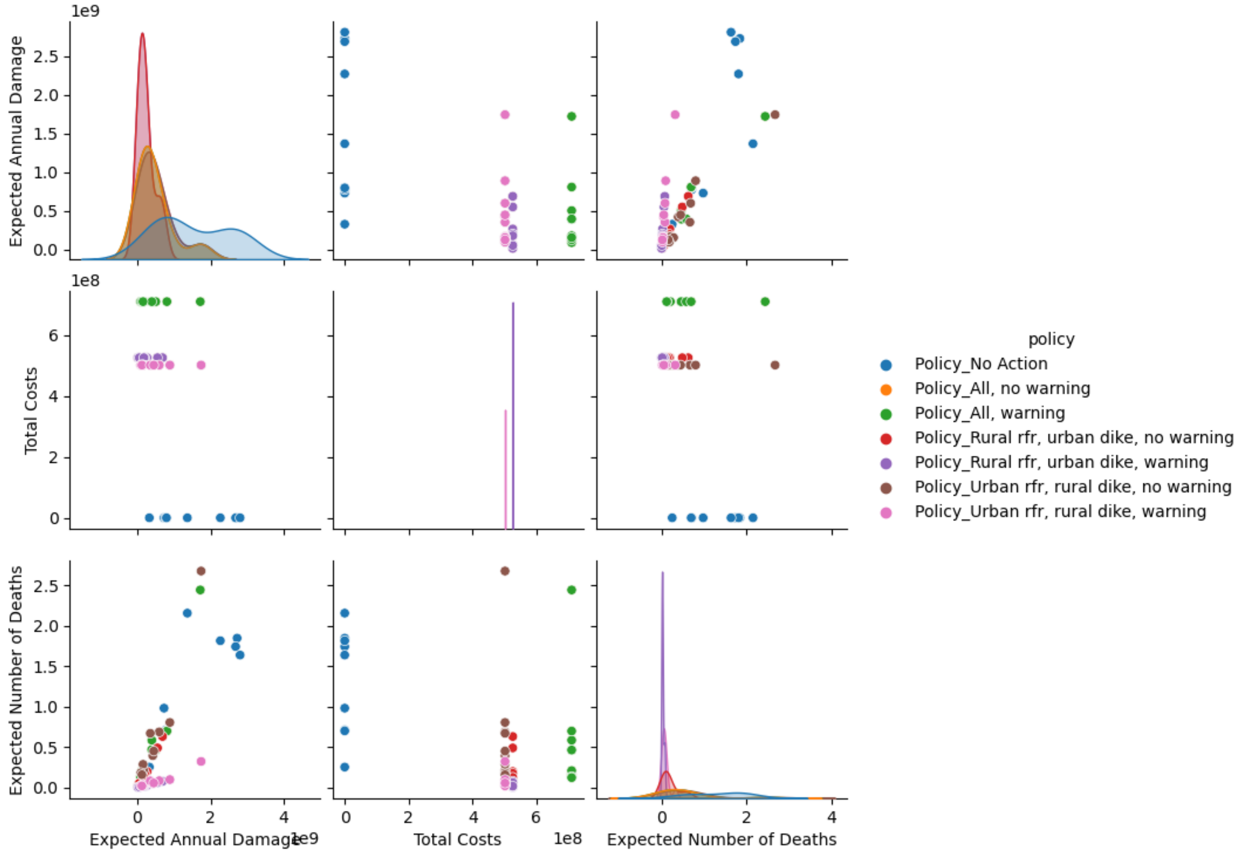

Figure 10.1: Pair plot of the open exploratory modeling for the EWS system for all scenarios.