Model-based decision making

Introduction

The central topic of this course is the support of long-term decision-making on complex societal issues through the use of cutting-edge modeling techniques in combination with state-of-the-art deliberative methods. These large societal issues are typically surrounded by deep uncertainty, and the various policy makers that are involved virtually always operate in a highly political environment. Analysts involved in model-based decision support need to be aware of this political context and need to be sensitive to the multi-actor aspects of decision making, hence the need for combining modeling and simulation with other methodological approaches.

This course aims to build a bridge between the modeling approaches as taught in the modeling line and the theories on decision making as taught in the policy analysis line. The course will on the one hand build on the recent work on model-based decision support for decision making under deep uncertainty. On the other hand, this course will cover recent work on contested knowledge claims, co-production of science-based policy, and deliberative policy analysis. The methods and techniques will be model based, but – and this makes this course unique – complemented with other types of methods aimed at generating support and creating legitimacy for model-based analyses.

The course will be a mix of workshops on key conceptual and theoretical issues, and group work of a more applied nature. Students will work in groups on a large societal issue, use models to support the design of an adaptive policy, and think about how to take account of the political environment in their designs, so as to contribute to alleviate the problem.

Learning objectives

After completion of this course, students can

- **Explain** basic concepts, theories and frameworks related to contested knowledge claims, co-production of science-based policy, deliberative policy analysis, decision making under deep uncertainty, and adaptive policy-making
- **Analyze** a given case in light of these basic concepts, theories and frameworks
- **Advise** on the appropriate ways in which model-based decision support can be intertwined with decision making processes in multi-actor settings, while accounting for the intrinsic political character of such processes.
- **Explain** exploratory modeling and scenario discovery
- **Apply** exploratory modeling and scenario discovery in support of adaptive policy design for a given case, and, on that basis, render advice to policy makers

- **Reflect** on the effects of their policy advice, possible limitations, as well as risks, given the context in which they operate, and in view of the ultimate objective of creating public value through more effective and legitimate policies and decisions
- **Complement** quantitative methods with qualitative methods such as elite interviewing or mixed-methods such as serious gaming, so as to take the perspectives of policy makers and decision makers into account and generate support for their advice

Assessment

The assessment of this course is based on a project. Details on the project can be found at the end of this document. The basic idea is that you will work on this project in groups of 4-5 students. The aim of the project is to develop a flood risk management strategy for the IJssel river in the Netherlands. Each group will be assigned a specific role. They are tasked with designing a strategy in line with their assigned role but in light of the multi-actor complexity of the case. As part of this project, there will be two debates. We are preparing these to also take place online.

Structure of the course

The basic structure of the course is shown in

Table 1. Despite that the course will be taught online, we plan to adhere to this structure as much as possible.

The theory lectures will be replaced with one or more short videos explaining the core concepts. We will try to have these videos online around the time of the planned lecture as outlined in

Table 1. Any questions pertaining the theory are to be posted on the forum.

There are also lab sessions to work on assignments. You can work on these assignments in groups of 4-5 students. These groups are the same as for the final project. Each group will be assigned to a teaching assistant. As a group, you can have an online video conferencing meeting with your TA for about 20 minutes once a week. Any questions pertaining the assignments are preferably first posted on the forum. The assignments themselves can be found on https://github.com/quaquel/epa1361_open.

The lab assignments have to be handed in by each group and will be assessed on a pass-fail basis. Not submitting is an automatic fail. They serve as a formative assessment and failing them won't influence your grading on the final project. But, from prior experience, we know that not working seriously on these assignments severely affects the quality of the project. After each deadline, model-answers for the assignments will be submitted to the GitHub repository.

Once a week, on a timeslot that is still to be determined, there will be about a 1-hour online lecture. Here Jan Kwakkel, the main lecturer of this course, will address any questions that have come up either on the forum or with the teaching assistant. Depending on technology, there will also be room to ask questions during this online lecture.

Table 1. Course program. The dark blue activities focus on exploratory modeling. The orange activities focus on the politics of decision making, and the green weeks are the exam period

		Monday	topic	Thursday	topic	Friday
17	1	20-04	Introduction, case, and setting up the workbench	23-04	Role of science and knowledge in decision making	
18	2			30-04	Supporting decision making under deep uncertainty	Deadline assignments week 1-2, 01-05, 17:00.
19	3	04-05	Open Exploration scenario discovery	07-05	(Big) data in policymaking	
20	4	11-05	Open Exploration global sensitivity analysis	14-05	Room for the River: Implications for decision-making	Deadline assignments week 3-4, 15-05, 17:00.
21	5	18-05	Directed Search many objective optimization			
22	6	25-05	Directed Search robustness considerations	28-05	adaptive policies / adaptation pathways	Deadline assignments week 5-6, 29-05, 17:00.
23	7			04-06	Student debate	
24	8	08-06	decision support	11-06	Student debate	
25	9	15-06				Deadline final assignment 19-06, 17:00.
26						
27						

Week 1

Lecture 1: Introduction

This week offers a broad introduction to the course. In this week we focus on the various problems encountered on the interface of modeling and political decision making. In addition, time is made available to ensure that everyone is up and running with the exploratory modeling workbench. This is an open source Python library that will be used throughout this course.

Literature

Walker, W.E., Marchau, V.A.W.J., Kwakkel, J.H., (2013) Uncertainty in the framework of Policy Analysis, in: Thissen, W.A.H., Walker, W.E. (Eds.), Public Policy Analysis: New Developments. Springer, Berlin, Germany.

Sarewitz, D. (2004) How science makes environmental controversies worse. Environmental Science & Policy 7, 385-403. doi: 10.1016/j.envsci.2004.06.001

Further optional reading

Oreskes, N., Shrader-Frechette, K., & Belitz, K. (1994). Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences. *Science, 263*(5147), 641-647.

Oreskes, N. (1998). Evaluation (Not Validation) of Quantitative Models. *Environmental Health Perspectives, 106*(6), 1453-1460.

Lecture 2: Role of science and knowledge in decision making

During this lecture we discuss the role of science-based models and knowledge in real-world decision-making. We discuss how assumptions behind models and the policy-relevant information gained with them may be ignored or questioned. Using the Dutch LCA case, we discuss why a good report doesn't necessarily have any impact on decision-making. Decisions are made in a complex policy battle wherein some actors participate and others do not, wherein some win and others loose. . Actors have incentives to behave strategically and use any power source when felt applicable, in which science-based models may be nothing more than a resource.

Literature

Stirling, A. (2010). Keep it complex. *Nature*, 468, 1029-1031.

Turner, S. (2005). Expertise and political responsibility: The Columbia Shuttle catastrophe. In: Maasen, S. & Weingart, P. (Eds.), *Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision-Making*. Sociology of the Sciences, vol. 24. (101–121). Dordrecht: Springer.

Kogan, M. (1999) "The Impact of Research on Policy", in F. Coffield (ed.) *Research and Policy in Lifelong Learning*, Bristol: Policy Press

Van Enst, W., Driessen, P., & Runhaar, H. (2014). *Towards Productive Science-Policy Interfaces: a Research Agenda. Journal of Environmental Assessment Policy and Managemen*t, 16(1), doi: 10.1142/S1464333214500070

Further reading

Tversky, A. & D. Kahneman (1985) "The framing of decisions and the psychology of choice", *Environmental Impact Assessment, Technology Assessment, and Risk Analysis*, vol.4 of the NATO ASI Series, 107-129

Rittel, H. W. J., & Webber, M. W. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences, 4*(2), 155-169.

Ackoff, R. A. (1979). The Future of Operational Research is Past. *The journal of the Operational Research Society, 30*(2), 93-104.

Week 2

Lecture 3: Supporting decision-making under deep uncertainty

This week offers an introduction to exploratory modeling in general and its use for supporting decision making known as robust decision making. A general taxonomy is presented, and we discuss how this taxonomy maps to the exploratory modeling workbench. The assignments focus on performing the basic steps of exploratory modeling, as well as using some more advanced features of the workbench.

Literature

Kwakkel, J.H. & Haasnoot, M. (2019) *Supporting decision making under deep uncertainty: a synthesis of approaches and techniques*, in Decision Making Under Deep Uncertainty – From Theory to Practice, Marchau, V.A.W.J., Walker, W.E., Bloemen, P, Popper, S.W. (eds).

Bankes, S. C. (1993). Exploratory Modeling for Policy Analysis. *Operations Research, 4*(3), 435-449.

Further reading

Bankes, S. C. (2002). Tools and Techniques for Developing Policies for Complex and Uncertain Systems. *Proceedings of the National Academy of Sciences of the United States of America, 99*(3), 7263-7266.

Lempert, R. J. (2002). A New Decision Sciences for Complex Systems. *Proceedings of the National Academy of Sciences of the United States of America, 99*(3), 7309-7313. doi: 10.1073/pnas.082081699

Maier, H. R., Guillaume, J. H. A., van Delden, H., Riddell, G. A., Haasnoot, M., & Kwakkel, J. H. (2016). An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? *Environmental Modelling & Software, 81*, 154-164. doi:10.1016/j.envsoft.2016.03.014

Week 3

Lecture 4: Open exploration – scenario discovery

A key phase in robust decision making is understanding when and how various sources of uncertainty negatively affect the performance of a candidate strategy. This is known as vulnerability analysis. There are two broad families of techniques: subspace partitioning and global sensitivity analysis. This week, we start focus on subspace partitioning

Literature

Bryant, B. P., & Lempert, R. J. (2010). Thinking Inside the Box: a participatory computer-assisted approach to scenario discovery. *Technological Forecasting and Social Change, 77*(1), 34-49. doi: 10.1016/j.techfore.2009.08.002

Taylor AL1, Hickey TJ, Prinz AA, Marder E. (2006) Structure and visualization of high-dimensional conductance spaces, Journal of Neurophysiology, 96: 891–905, 2006.

Note:: only focus on understanding the method, no need to focus on the domain specific details

Further reading

Lempert, R.J., Groves, D.G., Popper, S.W., Bankes, S.C. (2006) A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios. Management Science 52, 514-528.

Kwakkel, J. H., & Jaxa-Rozen, M. (2016). Improving scenario discovery for handling heterogeneous uncertainties and multinomial classified outcomes. *Environmental Modelling & Software, 79*, 311-321. doi: 10.1016/j.envsoft.2015.11.020

Hidayatno, A., Jafino, B. A., Setiawan, A. D., & Purwanto, W. W. (2020). When and why does transition fail? A model-based identification of adoption barriers and policy vulnerabilities for transition to natural gas vehicles. *Energy Policy, 138*. doi:10.1016/j.enpol.2020.111239

Lecture 5: (Big) data in policymaking

In this lecture we will focus on a specific part of the interface between science and policy: How data (or empirical evidence generally) enters and influences public decision-making. To illustrate this we will focus on big data as a trend that exemplifies (and exacerbates) some of the problems of using data to support decision-making in a political context. The key challenge with big data is usually not the sheer size, but rather that deriving insight from them requires an analytically novel method and many inherently political choices to be made along the way - much like it can be in exploratory modeling. This lecture will present some thought-provoking real-world examples of important political choices underlying technical analysis, as well as what that means for analysts and their role in policymaking.

Literature

Kettl, D. (2016) "Making Data Speak: Lessons for Using Numbers for Solving Public Policy Puzzles." *Governance*. Vol. 29, No. 4, 573–579.

Weiss, C. H. (1979). "The Many Meanings of Research Utilization." *Public Administration Review*, *39*(5), 426–431.

Crawford, K., K. Miltner & M. Gray (2014) "Critiquing Big Data: Politics, Ethics, Epistemology", *International Journal of Communication*, 8, 1663-1672

Further reading

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. Futures, 25(7), 739 - 755.

Athey, S. (2017) "Beyond prediction: Using big data for policy problems", *Science*, 355,483-485

Janssen, M. & G. Kuk (2016) "The challenges and limits of big data algorithms in technocratic governance", *Government Information Quarterly*, 33, 371–377

Höchtl, J., P. Parycek & R. Schöllhammer (2016) "Big data in the policy cycle: Policy decision making in the digital era", *Journal of Organizational Computing and Electronic Commerce*, *26*(1–2), 147–169

Week 4:

Lecture 6: Open exploration – global sensitivity analysis

A key phase in robust decision making is understanding when and how various sources of uncertainty negatively affect the performance of a candidate strategy. There are two broad families of techniques for this so-called vulnerability analysis. Last week, we focused on subspace partitioning. This week, we focus on global sensitivity analysis.

Literature

Saltelli, A., Aleksankina, K., Becker, W., Fennel, P., Ferretti, F., Holst, N., Wu, Q. (2019). Why so many published sensitivity analyses are false: A systematic review of sensitivity analysis practices. *Environmental Modelling & Software*, 114, 29-39. doi:10.1016/j.envsoft.2019.01.012

Cariboni, J., Gatelli, D., Liska, R., & Saltelli, A. (2007). The role of sensitivity analysis in ecological modelling. *Ecological Modeling, 203*, 167-182. doi: 10.1016/j.ecolmodel.2005.10.045

Jaxa-Rozen, M., & Kwakkel, J. H. (2018). Tree-based ensemble methods for sensitivity analysis of environmental models: A performance comparison with Sobol and Morris techniques. *Environmental Modelling & Software, 107*, 245-266. doi:10.1016/j.envsoft.2018.06.011

Further reading

Saltelli, A., & Annoni, P. (2010). How to avoid a perfunctory sensitivity analysis. *Environmental Modelling & Software*, 1508-1517. doi: 10.1016/j.envsoft.2010.04.012

Pianosi, F., Beven, K., Freer, J., Hall, J. W., Rougier, J., Stephenson, D. B., & Wagner, T. (2016). Sensitivity analysis of environmental models: A systematic review with practical workflow. *Environmental Modelling & Software, 79*, 214-232. doi:10.1016/j.envsoft.2016.02.008

Lecture 7: Room for the River: Implications for decision-making

This lecture will introduce the 'Room for the River' (RfR) project – project that changes the paradigm on water management in the Netherlands and does so both in terms of engineering and decision-making. Since the bulk of this course deals with the engineering implications of such approach, this lecture provides general background as well as the decision-making implications that RfR brought about. Given that these implications are mainly challenges, the main goal of the lecture is to illustrate how these can be (and have been) overcome. Lastly, this lecture will also introduce the student debate that loosely mirrors the decision-making and engineering context of RfR for the river Ijssel.

Literature

Rijke, J., van Herk, S., Zevenbergen, C., & Ashley, R. (2012). Room for the river: Delivering integrated river basin management in the netherlands. *International Journal of River Basin Management*, *10*(4), 369–382.

Schut, M., Leeuwis, C., & van Paassen, A. (2010). Room for the river: Room for research? The case of depoldering De Noordwaard, the Netherlands. *Science and Public Policy*, *37*(8), 611–627.

Further Reading

De Bruijn, H., De Bruijne, M., & Ten Heuvelhof, E. (2015). The politics of resilience in the Dutch 'Room for the River'-project. *Procedia Computer Science*, 44(C), 659–668.

Klijn, F., de Bruin, D., de Hoog, M. C., Jansen, S., & Sijmons, D. F. (2013). Design quality of room-for-the-river measures in the Netherlands: role and assessment of the quality team (Q-team). *International Journal of River Basin Management*, *11*(3),

Week 5:

Lecture 8: directed search: many objective optimization

Vulnerability analyses rely on sampling. An alternative way to search through a large combinatorial space is to use (many objective) optimization. This week we introduce this search strategy and discuss the various ways this family of techniques can be used to support decision making under deep uncertainty. We focus specifically on the use of many-objective optimization for finding promising strategies conditional on a reference scenario, and the use of many-objective optimization for worst case discovery.

Literature

Maier, H. R., Razavi, S., Kapelan, Z., Matott, L. S., Kasprzyk, J. R., & Tolson, B. (2019). Introductory overview: Optimization using evolutionary algorithms and other metaheuristics. *Environmental Modelling & Software, 114*, 195-213. doi:10.1016/j.envsoft.2018.11.018

Kasprzyk, J. R., Nataraj, S., Reed, P. M., & Lempert, R. J. (2013). Many objective robust decision making for complex environmental systems undergoing change. *Environmental Modelling & Software, 42*, 55-71. doi:10.1016/j.envsoft.2012.007

Kasprzyk, J. R., Reed, P. M., & Hadka, D. (2016). Battling Arrow's paradox to discover robust water management alternatives. *Journal of Water Resources Planning and Management, 142*(2). doi:10.1061/(ASCE)WR.1943-5452.0000572

Further reading

Reed, P. M., Hadka, D., Herman, J. D., Kasprzyk, J. R., & Kollat, J. B. (2013). Evolutionary multi-objective optimization in water resources: The past, present, and future. *Advances in Water Resources, 51*, 438-456.

Halim, R. A., Kwakkel, J. H., & Tavasszy, L. A. (2016). A scenario discovery study of the impact of uncertainties in the global container transport system on European ports. *Futures, 81*, 148-160. doi:10.1016/j.futures.2015.09.004

Week 6

Lecture 9: directed search: robustness considerations

Last week, we used many-objective optimization to find promising strategies conditional on a reference scenario. However, we are interested in both good performance in individual scenarios as well as good performance over a set of scenarios. How can we include the latter, also known as robustness, within the search for promising candidate solutions? For this, we first look at various robustness metrics and their relative merits. We discuss various strategies for including robustness considerations in the search phase of many-objective robust decision making and the merits of these strategies.

Literature

Bartholomew, E., & Kwakkel, J. H. (2020). On considering robustness in the search phase of Robust Decision Making: A comparison of Many-Objective Robust Decision Making, multi-scenario Many-Objective Robust Decision Making, and Many Objective Robust Optimization. *Environmental Modelling & Software*, 127, 104699. doi:10.1016/j.envsoft.2020.104699

McPhail, C., H. R. Maier, J. H. Kwakkel, E. Giuliani, A. Castelletti and S. Westra (2018). Robustness metrics: How are they calculated, when should they be used and why do they give different results? *Earth's Future.* doi: 10.1002/2017EF000649

Further reading

Watson, A. A., & Kasprzyk, J. R. (2017). Incorporating deeply uncertain factors into the many objective search process. *Environmental Modelling & Software, 89*, 159-171. doi:10.1016/j.envsoft.2016.12.001

Eker, S., & Kwakkel, J. H. (2018). Including robustness considerations in the search phase of Many-Objective Robust Decision Making. *Environmental Modelling & Software, 105*, 201-2016. doi:10.1016/j.envsoft.2018.03.029

Kwakkel, J. H., Haasnoot, M., & Walker, W. E. (2016). Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for Model-Based Decision Support under Deep Uncertainty. *Environmental Modelling & Software, 86*, 168-183. doi:10.1016/j.envsoft.2016.09.017

Lecture 10: Adaptive Planning

In the previous weeks, the focus has been on various approaches for exploring and searching through the high dimensional uncertainty and lever space. This week, the focus switched to the structure of a plan. One response to uncertainty is to design policies that can be adapted over time in response to how the future actually unfolds. This week, we explore this idea in more detail. The assignments focus on using exploratory modeling to design adaptive plans.

Literature

Hamarat, C., Kwakkel, J.H., Pruyt, E., 2013. Adaptive Robust Design under Deep Uncertainty. Technological Forecasting and Social Change 80(3) 408-418, doi: 10.1016/j.techfore.2012.10.004

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change, 23*(2), 485-498. doi: 10.1016/j.gloenvcha.2012.12.006

Additional optional reading

Dewar, J. A., Builder, C. H., Hix, W. M., & Levin, M. H. (1993). *Assumption-Based Planning: A Planning Tool for Very Uncertain Times* (Report MR-114-A). Retrieved from Santa Monica, CA: http://www.rand.org/pubs/monograph_reports/2005/MR114.pdf

Zeff, H. B., Herman, J. D., Reed, P. M., & Characklis, G. (2016). Cooperative drought adaptation: Integrating infrastructure development, conservation, and water transfers into adaptive policy pathways. *Water Resources Research*. doi:10.1002/2016WR018771

Michas, S., Stavrakas, V., Papadelis, S., & Flamos, A. (2020). A transdisciplinary modeling framework for the participatory design of dynamic adaptive policy pathways. *Energy Policy, 139*. doi:10.1016/j.enpol.2020.111350

Week 7

Lecture 11: Student Debate

See the debate instructions

Week 8

Lecture 12: decision support

In the foregoing weeks, we focused on a wide variety of model-based analysis techniques. This week, we shift to how we can enable non-analyst to interact with the results from these techniques in order to support decision-making.

Literature

Tsoukiàs, A. (2008). From decision theory to decision aiding methodology. *European Journal of Operational Research, 187*, 138-161. doi:10.1016/j.ejor.2007.02.039

Gong, M., Lempert, R.J., Parker, A.M., Mayer, L.A., Fischbach, J.R., Sisco, M., Mao, Z., Krantz, D.H., Kunreauther, H. (2017) Testing the Scenario Hypothesis: An Experimental Comparison of Scenarios and Forecasts for Decision Support in a Complex Decision Environment. Environmental Modelling & Software 91, 135-144.

Pot et al (2018) What makes long-term investment decisions forward looking: A framework applied to the case of Amsterdam's new sea lock, *Technological Forecasting & Social Change*, 10.1016/j.techfore.2018.01.031

Kwakkel, J. H., Walker, W. E., & Haasnoot, M. (2016). Coping with the Wickedness of Public Policy Problems: Approaches for Decision Making under Deep Uncertainty. *Journal of Water Resources Planning and Management*. doi:10.1061/(ASCE)WR.1943-5452.0000626

Further reading

Woodruff, M. J., Reed, P. M., & Simpson, T. W. (2013). Many objective visual analytics: rethinging the design of complex engineered systems. *Structural and multidisciplinary optimization, 48*, 201-219. doi:10.1007/s00158-013-0891-z

Di Matteo, M., Dandy, G.C., Maier, H.R., 2017. A multi-stakeholder portfolio optimization framework applied to stormwater best management practice (BMP) selection. Environmental Modelling & Software 97 16-31, doi: 10.1016/j.envsoft.2017.07.012

Lecture 13: Student Debate

See the debate instructions

Description of the case study and the simulation model

The aim of the project is to develop a flood risk management plan for the upper branch of the IJssel River in the Netherlands. Roughly speaking, a flood is *an overflow of water that submerges land that is usually dry.* Flood risk management encompasses all actions aiming to both prevent the flood event from happening and limit the damage when flood happens.

Possible management measures differ widely in costs and scope and flood management planning is barely only about floods. For example, roads are usually built on top of a dike and increasing the capacity of a river may require a substantial rethinking in the design of the nearby urban area. In addition, land use restrictions (e.g. not to build close to a river) will in fact affect the economic growth potential of a given area. In addition, it's easy to realize that conflicts between the interests of riverine communities may emerge. Upstream communities, which are those being hit first by the event, would tend to raise their levels of protection (e.g. by raising dikes). In so doing, however, higher water levels may be caused downstream. Downstream communities, in turn, would benefit from upstream flood management measures aiming at reducing the volume of water flowing in the river. Very often rivers cross regional and/or national boundaries which make this issue harder to solve. One must therefore keep in mind the multiple values involved when deciding upon flood risk management measures, most of which are hard to quantify. In addition to assessing risk (which is the main task of this exercise) a thorough policy discussion must follow.

Students will be provided with a simulation model that assess economic damage and number of casualties at several locations located along the IJssel river. The case study is shown in Figure 1. There are five locations of interest (i.e. Doesburg, Cortenoever, Zupthen, Gorssel and Deventer) each located within a different dike ring (i.e. ring-shaped dikes which protect a flood-prone area). As one can infer from the red shades of the land use map (right hand picture in Figure 1), Zutphen and Deventer are major urban areas with the remaining ones being relatively rural.

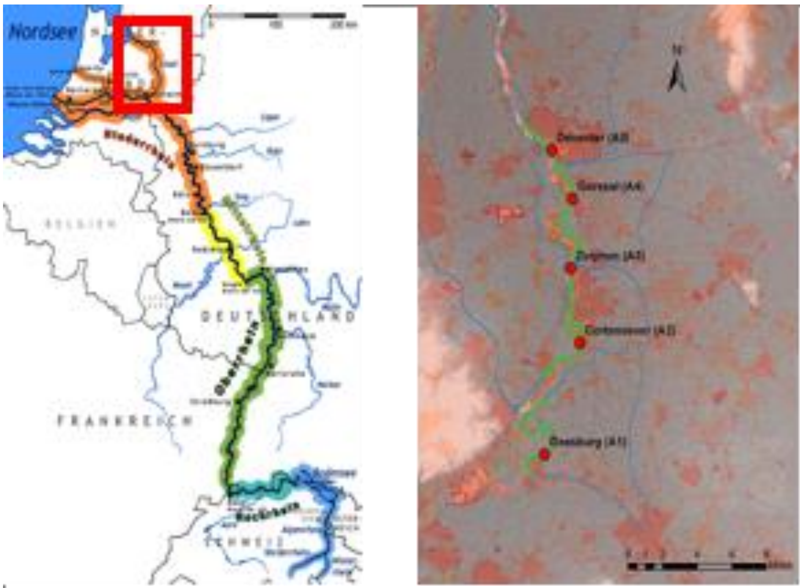


Figure 1 Left: The Rhine River. Right: The upper IJssel River, with locations of interest in red and the relative dike stretch in green. Dike rings are depicted in blue.

Figure 1

Briefly speaking, the model simulates the propagation of the [flood hydrograph] throughout the river channel. At each location, the response of the dike system is assessed. This requires simulating whether the dike will fail and, in case, the growth of the [breach width] in time. If the dike fails, then flood occurs and an estimation of economic damage and number of casualties is carried out. By running the model with different (combinations of) flood risk management measures, one can explore their effect in terms of e.g. risk reduction and risk distribution across areas.

The simulation model follows the XLRM framework (Figure 2):

X, external factors: uncertainties affecting the performance of the system under, which the policy maker has little or no control on.

L, levers: set of policies under study (i.e. decision variables).

R, relationship:set of rules/mathematical expressions linking X to L for computing M.

M, measures: indicators assessing the performance of the levers (i.e. decision objectives).

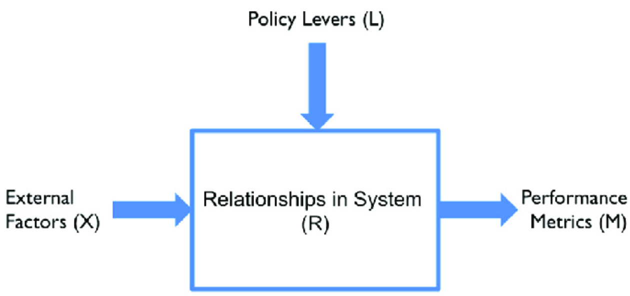


Figure 2 The XLRM framework

The following tables list the XLM factors of the model. The R factor is the model itself.

X			
Factor	**Description**	**Range/set**	**Unit**
Flood wave shape	A normalized curve describing the way discharges at the most upstream location change over time. There are 140 possible wave shapes.	0-140	
Dike failure probability[1]	Probability that the dike will stand the hydraulic load. The higher this number, the 'stronger' the dike.	0-1	
Final breach width[1]	The final extent of the breach width. The larger the width, the greater the volume of water flowing into the floodplain.	30-350	m
Breach width model	The way the breach width develops over time, with the uncertainty being the growth rate. The final breach width can be reached within 1,3 or 5 days.	(1, 1.5, 10) for 5,3,1 day respectively	1/day
Discount rate[2]	It determines the present value of the future expected damage. The lower the value, the more damage to future generations is valued.	(1.5, 2.5, 3.5, 4.5)	

Figure 3 The X factors of the simulation model.

L			
Factor	**Description**	**Range**	**Unit**
Dike heightening[1,2]	Amount of dike raising. The higher the dike, the higher the hydraulic loads it can stand.	0-10	dm
Early warning	Early warning systems anticipate a threat and help limiting damage and/or avoiding deaths. The earlier the alert, the more effective the response, but also the more uncertain it is that the event will actually happen. False alerts can be costly and undermine people's trust into the authority. Waiting too long is also problematic as the efficacy of late alerts is poor. In the model you can choose how much time in advance to give the alert.	0-4	days
Room for the River[2]	RfR projects widen the river bed thus lowering the water levels associated to a given water volume. There are five RfR projects which can be either implemented or not (1 or 0). Each project corresponds to a profile of water level reductions across locations.	0-1	

Figure 4 The L factors of the simulation model.

M			
Factor	**Description**	**Range**	**Unit**
Expected annual damage[1,2]	Expected annual value of flood damage over the planning period. Clearly, for each location, the lower this value, the better.		€
Expected number of casualties[1,2]	Same as above but related to amount of casualties and not economic damage.		
Dike investment costs[1,2]	Investment costs of raising dikes.		€
Evacuation costs	Function of the number people evacuated and the number of days they need to be out from home. The estimation is based on the 1995 evacuation in the Netherlands.		€
Room for the river costs	Investment costs of the implemented Room for the river project.		€

Figure 5 The M factors of the simulation model.

1 The factor applies to each location, i.e. there are five factors, with potentially different values.
2 The factor applies to each of the planning steps, i.e. there are as many as factors as the considered planning steps, with potentially different values.

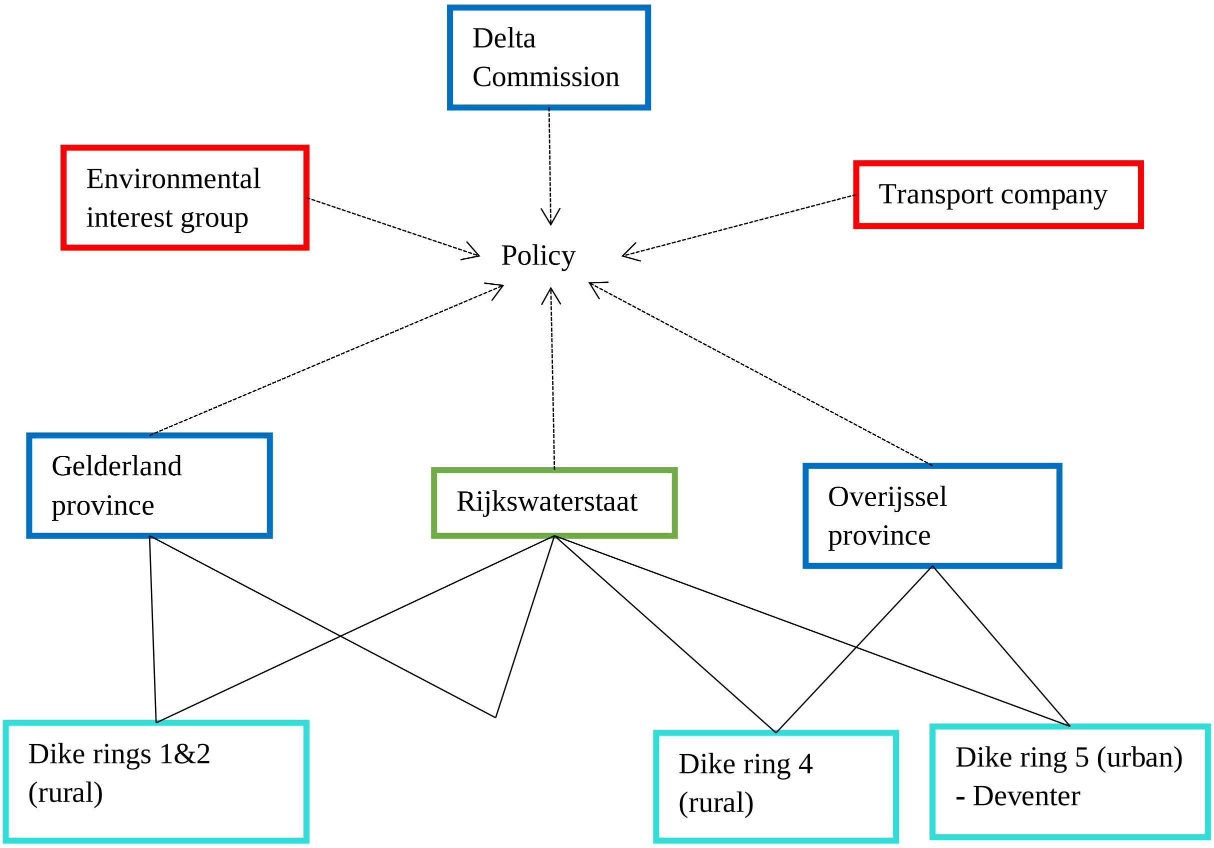
EPA1361 Model-based decision-making debate

In this debate exercise each student group will represent an actor involved in designing a robust long-term policy solution to manage flood risk on the Ijssel river. The purpose of this debate is to prepare you for the 'political reflection' part of your final assignment, in which you are meant to describe how your proposed solution interacts with the dynamics of political decision making and what can you do to make it impactful. Each group will represent an actor and have a specific set of goals with regards to the solution 'adopted' in the final debate. In pursuing these goals, you will have a chance to see how some of the theoretical concepts you have been taught prior to this course and during this course play out in reality, as well as understand how a specific scenario makes a decision-making process unique in important ways.

That said, this debate is based on a **stylised** version of reality - reality which is even messier, more complex and in some ways simply different. In other words, the ideal real-world solution might not be the ideal solution for this exercise, but you can still explore the strategies used in the real-world Ijssel river case and you can refer to the real-world case in writing your political reflection. What is important to note here is that the political reflection part of your final assignment is **NOT** specific to the debate itself - the debate exists to illustrate key concepts and give you good ideas, but you need to generalize those beyond what your classmates do in the debate.

Actor constellation:

There are 10 main actors in this debate, 6 of which will take direct part in the final debate at the end of which a vote will be taken to either recommend a policy to the parliament or to ask for an extension (in case an agreement on policy cannot be reached). In the following diagram blue outline designates a mainly political actor, green an administrative (technocratic) actor, cyan a combination of political and administrative actor, and red a special interest actor. Dashed lines represent taking part in the final policy deliberation and full lines represent an official link between two actors. In this case, the dike rings will not take part in the final debate, but their interests will be represented by provincial governments and by Rijkswaterstaat.



Student groups not assigned to represent one of these actors will be 'analyst' groups employed by one of the main actors. As such, analysts do not really have a political agenda and are mainly motivated by customer satisfaction. That said, the actor that hired the analyst can try and use them however they like (for example by allowing another actor to make use of the analyst as a bargaining chip or as a way to illustrate the impartiality of analysis). Should ethically unsavoury, illegal, or heavily political dilemmas arise, it is up to the analysts to decide how far they are willing to go in service of their client.

Actor assignment:

The student groups for this assignment are the same groups as for the final assignment and participation in this assignment is mandatory. Actor assignment will happen following the lecture on 14th of May that will introduce the case.

On 14th of May at exactly 16:00 local time actor assignments will open and will be on a **first-come-first-served basis**! This will be done via Brightspace using group self-enrolment (Collaboration - Group Self Enrolment - Category: Actor Assignment) and the feature will automatically open at 16:00. to avoid multiple groups enrolling as one actor only one student will be able to register per each actor - please decide on which actors you are interested in beforehand and designate only one of you to try and enrol as the actor(s) you are interested in. If you are placed on a waiting list for an actor it means someone was faster than you and you have to leave the waiting list and register for a different actor. **Waiting lists will not be**

taken into account, they are simply a feature that cannot be disabled. You will have 24 hours to have the designated person enrolled as one of the actors. On Friday May 15th the self-enrolment will be closed and what your representative was enrolled in becomes your actor. **Make sure your group already exists as a Brightspace group beforehand** because we will distribute the actor mandates and generate a list of who represents each actor based on existing Brightspace groups. Once groups are assigned to actors who you represent will become public knowledge (published on Brightspace) so that you always know which of your peers represent an actor you are interested in reaching out to.

The mandate given to you is secret and you cannot show it to other groups! You can of course be very open about your intentions, but you cannot prove your honesty by revealing your mandate (much like in reality).

Debate structure:

Stage 1: Debate introduction (May 14th lecture):

Debate will be introduced by briefly outlining the main organizational points and relating it to the lecture of that day. The following day actor assignments will be finalized, but if you managed to enrol as an actor (not in a waiting list) you will be representing that actor.

Stage 2: Strategy building (homework):

Read through your mandates, devise a (preliminary) strategy and start any alliance building and negotiating with relevant parties in whatever format you find appropriate.

Stage 3: Preliminary debates (13:15 - 14:00 during 4th of June lecture):

Three separate loosely structured debates happen. The structure will be rather informal with no rules on procedure (such as time to speak, interject, etc.). However, these meetings will keep an 'official record' as notes to be distributed to those present in the meeting after it concludes (and to s.vydra@tudelft.nl). These notes will not be made public to other actors, but they do not have to be kept secret either: Actors can exchange these and make them available to whoever they wish. These notes can be referred to in the official debate. The three debates will be the following:

- Gelderland: Province of Gelderland (in charge of hosting and notes), Dike rings 1 & 2, Dike ring 3
- Overijssel: Province of Overijssel (in charge of hosting and notes), Dike ring 4, Dike ring 5
- High-level strategy meeting: Rijkswaterstaat (in charge of hosting and notes), Delta Commission, Transport company, Environmental interest group

These three meetings will be held online using virtual classrooms in Brightspace.

Stage 4: Policy building (14:00 - 15:00 during 4th of June lecture):

Further analysis, co-ordination and alliance forming between actors. Do your best to be reachable by other groups: Have access to your email and be ready to arrange videoconference meetings with other actors. The platform and exact ways of communicating are up to you.

Stage 5: Preliminary policy debate (15:00 - 15:30 during 4th of June lecture):
This is a preliminary meeting of the final debate, which opens with the Rijkswaterstaat having 5-10 minutes to present a policy (if they have one already), or at least outline their priorities and their policy direction. The structure of this short debate will follow that of the final debate (see below) and will mainly aim to allow each actor to voice concerns/support about the direction the Rijkswaterstaat is heading in proposing a policy solution. Observers can also see how the actors present in the final debate conduct themselves. This will also be done using virtual classrooms on Brightspace

Stage 6: Policy building (homework):
Further negotiation and analysis time. The Rijkswaterstaat also needs to come up with a policy proposal to present at the start of the final session - a policy that should already have a broad support.

You are required to submit a short reflection (one page) before midnight on June 10th, reflecting on a) your actual goals for the policy solution (as specific as possible), b)who you think are your allies and why, c) who you think will oppose you and why, d) what is your strategy to achieve your goals in the final debate. If you are an analyst reflect instead on a) how you were utilised in the political process, b) what should your employer do differently to make best use of you and why, c) what do you think of their chances going into the final debate. This short reflection will not be graded, but it is compulsory for you to submit one. Needless to say, writing a good short reflection will provide you with a strong foundation for reflecting on the political feasibility in the final assignment. Submit your reflections by e-mail to s.vydra@tudelft.nl

Stage 7: Final policy debate (13:15 - 15:30 during 11th of June lecture):
In this final debate six actors will be present: Rijkswaterstaat, Delta Commission, Gelderland province, Overijssel province, transport company, and environmental interest group. This debate will once again take place using virtual classrooms in Brightspace. Each of these six actors will be represented by one person who will be actively contributing to the debate (via audio and video). However, that person can ask for other representatives to be given the floor to make a point, following which they will be given permission to enter the conference call via audio, video, and screen sharing.

The rest of the class will join as spectators in the virtual classroom and will use whatever communication channels they want to provide information and arguments to those actually speaking in the debate. Those of you not actually speaking in the debate can still run analysis, talk to other parties, and curate the most important bits of information to the speaker.

The debate will be moderated. You will have to raise your hand (on your camera feed) to be given the space to make your own point or to respond to a point someone else made. If an actor is directly targeted by a statement, they will be given the time to respond immediately. The time to make an individual point will be limited to a maximum of three minutes. Actors can also present their own materials and analytical outputs in this conference - virtual classrooms allow for the sharing of an entire screen or a specific application you are running so feel free to prepare a few illustrations if they help you make your points.

The final debate session will have the following structure:
10 minutes: Rijkswaterstaat presents the policy/policies they designed, including expected results. It is expected that a summary of the proposed policy/policies will be disseminated to all actors before the debate.
40 minutes: First round of debate
30 minutes: Break during which actors in the debate can consult their analysts, negotiate with other actors, etc.
40 minutes: Second round of debate
10 minutes: Rijkswaterstaat has the opportunity to update and finalize their policy proposal if they want to. The proposal is then voted on. The six actors present each have a vote and the **Rijkswaterstaat and Delta Commission have veto powers** – they can invoke said powers to scrap the policy proposal regardless of the agreement from other actors. **A majority of four votes** is necessary to approve the policy, but the broader support the policy has the more likely it is to be adopted by the parliament.

Stage 6: De-brief (15 minutes to end June 11th lecture):
We will de-brief on the entire process of the debate and highlight good strategies that we saw throughout the debate implemented to overcome some of the public decision-making dynamics. We will also highlight some of the strategies that succeeded in de-valuing models and analysis in favour of political and value-based arguments (and how those could have been overcome better). This might be challenging to do given the online nature of this year's debate, but we will try.

Final assignment

The final assignment is to develop a plan for the IJssel river case study to cope with flood risk, using the provided simulation model. The final report should contain two parts: a **model-based analysis** resulting in an advice, and a **reflection** on this advice.

The assignment is group work. Groups should ideally be composed of 5 persons. You can self-organize in to groups. Be careful to ensure a mix of capabilities.

Part 1: Model based analysis and advice

The aim of the assignment is that you show that you can structure a messy decision problem, analyze it using carefully selected exploratory modelling techniques, and on the basis of these analyses render advice to policy makers. The report should be written for a technically minded audience. A rubric that is used in grading is given in Table 2. 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 (may be a link to a repository on github or a zipfile shared using a file transfer service).

Suggested outline

The final report should be kept short and to the point. Aim for the main text to be somewhere around 10-20 pages, or 5000-7500 words (excluding figures and tables). Note that this is a soft constraint. A suggested outline is the following:

1. **1-page summary** with advice for problem owner; what advice do you give the problem owner and why? This advice should be understandable for a general audience unfamiliar with deep uncertainty methods and techniques.
2. **Problem framing**; the decision problem can be structured in many ways. How are you framing the problem? What do you see as the key objectives and constraints? What levers are relevant, and what is being treated as uncertain. It is important to show an awareness of the political arena within which your problem owner is operating. It is also possible to entertain more than one problem formulation.
3. **Approach**; What selection of deep uncertainty methods are you using, in what order, and why? This should be clearly motivated and grounded in the literature
4. **Results**; this should be a readable summary of the results from applying the approach. Don’t pursue death by figures but carefully select what visualizations (figures, tables) are functional for telling your story and logically lead to the main conclusions and policy advise?

5. **Discussion**; what are key threats to validity of your conclusions? What directions do you see for further refining or improving your analysis? Again, this should be grounded in literature and/or an awareness of the decision arena.
6. **Conclusions**; a more extended conclusion grounded in your results and discussion, leading to a clear advice for your problem owner.

Code and analyses

The code and analyses are an integral part of the final assignment. The primary focus of grading is on reproducibility of the results. Some questions that might help you critically review your code and its reproducibility"

- Is there a readme that explains dependencies and repository structure?
- Are the dataset(s) required to reproduce the advice included?
- Can all figures and tables used in the report be traced to specific notebooks?
- Is the code itself annotated?
- Is the call signature documented?
- Are results from code interpreted?
- Is the analysis process tractable based on the provided notebooks/scripts?
- Does the code abide by pep8 (https://www.python.org/dev/peps/pep-0008/) and the Numpy doc standard (https://numpydoc.readthedocs.io/en/latest/format.html) ?

Jupyter notebooks stimulate the use of a literate computing workflow. This means that you can interleave code, its outputs, text, and latex style equations. Ideally when sharing notebooks with others, it allows you to follow along with their thinking. Prior to any code, there should be readable text motivating the code that is to follow and any pointers for understanding the code. Next, the code is given with possible inline comments for further readability. Next, the output of the code is shown as a figure or table. This is followed by text interpreting these results: what does it mean or imply? Often a given result gives rise to new thoughts, questions, or threats to validity. To address these a next analysis step is used. Since Jupyter notebooks support markdown, headings, bullets and numbering can be used to further outline a given notebook.

My personal workflow when working with the workbench is to have the generation of results in .py files which I run using an Interactive Development Environments like PyCharm (my suggested IDE), Spider (comes with Anaconda), or Eclipse with Pydev (my personal choice for historic reasons). I typically don't perform large series of experiments or optimizations within notebooks because of parallelization. I also like to separate the generation of the results from the analysis of the results.

Table 2 Rubric for model based analysis and advice

		Insufficient	Weak	Sufficient	Good	Excellent
report	**Summary**	No advice	Unclear advice or advice not understandable to a non-expert	Clear advice that is understandable to the non-expert	Clear understandable advice grounded in multi-actor context	Convincing advice in light of multi actor context, understandable for non-experts
	Problem framing	No clear framing of the problem	Very limited naïve framing of the problem without any awareness of the policy arena	Sensible framing of problem in light of problem owner	Attention for perspective of multiple key actors in how problem is framed	Explicit framing of problem from multiple relevant perspective (i.e. rival framings)
	Approach	Selection of only a single technique, no grounding in literature	Limited selection of techniques, not embedded in a broader workflow, and poorly grounded in relevant literature	Standard application of deep uncertainty approach (e.g. RDM) grounded in relevant literature and motivated in light of problem framing	Analysis is carried out for multiple problem framings or relies on state-of-the-art deep uncertainty techniques and motivated in light of problem framing	Analysis is carried out across the explicated rival problem framings and relies on state-of-the-art deep uncertainty techniques
	Results	Death by graphs, tables or code, no narrative, and/or inconsistent with approach	Limited story, to many graphs in main text.	Readable story, consistent with approach using well-chosen visuals and tables to support narrative	Readable story, consistent with approach using carefully designed visuals and tables to support narrative	Convincing story, consistent with approach using carefully designed visuals and tables to support narrative
	Discussion	No awareness of obvious limitations	Mentions limitations but only limited discussion of implications for conclusions	Identifies key limitations of the analysis and their implications for conclusions	Identifies key limitations of their analysis from both a methodological point of view and the policy arena point of view. Discusses their implications for conclusions	Identifies key limitations of their analysis from both a methodological point of view and the policy arena point of view. Discusses their implications for conclusions and

						suggests ideas for future work to overcome them
	Conclusions	Inconsistent conclusions not linked to problem owner.	Trivial conclusions consistent with analysis but not linked to problem owner	Conclusions are consistent with analysis and advice is appropriate for problem owner	Conclusions are consistent with analysis advice is appropriate for problem owner and the multi-actor context	Convincing conclusions consistent with analysis advice is appropriate for problem owner and the multi-actor context

Part 2: Political Reflection

Aim of this part of the assignment is to show your understanding of how the advice you develop translates into real-world decision-making. Using the assigned literature, your own research, as well as insights from the debate exercise, reflect on steps you have taken and would take to make your analysis useful in a 'messy' and 'political' decision-making process. I expect at least the following:

1. Reflect on some tensions and challenges that may adversely impact how the proposed advice is used in decision making. Keep in mind that to answer this you have to be clear about your role as analysts in the decision-making process, otherwise you cannot define what is 'improper' use of your analysis.
2. Based on these tensions and challenges, briefly outline what you have already accounted for in your analysis to ensure that the impact of these tensions and challenges is limited.
3. Based on these tensions and challenges, briefly outline what you would do and how you would behave to ensure that the impact of these tensions and challenges is limited.
4. Reflect on your strategy: Is what you have done and what you would do during the process sufficient to make sure your advice has the desired impact? How so? Are there other tensions and challenges that could also be problematic?

The reflection part of your report should also be kept short. Aim for a reflection approximately 2-5 pages in length. This is a soft constraint, but being concise and clear in your reflection will only help your grade. The grading criteria used to assess the political reflection are given in Table 3.

Table 3 Rubric for political reflection

	Insufficient	**Weak**	**Sufficient**	**Good**	**Excellent**
Reflecting on tensions and challenges that may impact how the report is used in political decision making.	Task is either completely or largely unaddressed	Some challenges are addressed but there are less than three distinct challenges and they are not described well	There are three or more distinct challenges identified, but their description is rather broad	There are three or more distinct challenges identified and described well. In describing them authors draw on the course literature and make these challenges specific to the context and proposed policy advice.	There are three or more distinct challenges identified and described well. In describing them authors draw on the course literature and general academic literature. These challenges are very clearly specified to the proposed policy advice using relevant literature and good arguments.
Outline what **you have already done** to mitigate the identified tensions and challenges	Task is either completely or largely unaddressed	There is a vague idea of some analytical steps being politically salient, but there is no coherent strategy.	Specific analytical steps are clearly identified as politically salient and linked to identified challenges. These are subsequently addressed.	Specific analytical steps are clearly identified as politically salient and linked to identified challenges. A clear strategy based on the role of the analyst is outlined and followed throughout.	Multiple specific analytical steps are clearly identified as politically salient and linked to identified challenges. A clear strategy based on the role of the analyst is outlined, supported by the literature, and followed throughout. The impact of these decisions in terms of analysis is explored and taken into account.
Outline what **you will still do in the decision-making process and how you will behave** to mitigate the identified tensions and challenges	Task is either completely or largely unaddressed	There is a vague idea of how technical advice can be 'improperly' used, but there is no coherent strategy.	There is a clear idea of how technical advice can be 'improperly' used. S strategy of proposed for dealing with this.	Specific strategies for how to behave in the decision-making process are linked to identified challenges. This is based on course literature and specific to the proposed policy advice.	Specific strategies for how to behave in the decision-making process are linked to identified challenges. This is based on course literature, general academic literature, the context of the Ijssel river, and very specific to the proposed policy advice.

Reflect on the proposed strategy by discussing potential risks associated with it. How well have you addressed the key challenges you identify? What are you missing that might also be important?	Task is either completely or largely unaddressed	Some risks addressed but not structured or clear	Some risks addressed appropriately and in detail	3 or more risks addressed appropriately and in detail, including justifications (using literature) for why these are difficult to address in this context.	3 or more risks addressed appropriately and in detail, including justifications (using literature) for why these are difficult to address in this context. Includes potential adaptations and exploration of the impact of those adaptations.