Department of Mathematics and Systems Analysis

Improving the practice of model based problem solving with a systemic behavioral perspective

Tuomas J. Lahtinen

Aalto University

DOCTORAL DISSERTATIONS

Aalto University publication series
DOCTORAL DISSERTATIONS 250/2017

Improving the practice of model based problem solving with a systemic behavioral perspective

Tuomas J. Lahtinen

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Science, at a public examination held at the lecture hall E of the school on 19 January 2018 at 12 noon.

Aalto University
School of Science
Department of Mathematics and Systems Analysis
Systems Analysis Laboratory

Supervising professors
Professor Raimo P. Hämäläinen, Aalto University
Professor Kai Virtanen, Aalto University

Thesis advisor
Professor Raimo P. Hämäläinen, Aalto University

Preliminary examiners
Professor Rudolf Vetschera, University of Vienna, Austria
Dr. Igor Linkov, US Army Engineer Research and Development Center, USA

Opponent
Professor Ralph Keeney, Duke University, USA

Aalto University publication series
DOCTORAL DISSERTATIONS 250/2017

ISBN 978-952-60-7774-1 (printed)
ISBN 978-952-60-7775-8 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)
http://urn.fi/URN:ISBN:978-952-60-7775-8

Unigrafia Oy
Helsinki 2017

Finland

Publication orders (printed book):
systems.analysis-ms@aalto.fi

441 697
Printed matter

Aalto University

Aalto University, P.O. Box 11000, FI-00076 Aalto www.aalto.fi

Abstract

Author
Tuomas J. Lahtinen

Name of the doctoral dissertation
Improving the practice of model based problem solving with a systemic behavioral perspective

Publisher School of Science

Unit Department of Mathematics and Systems Analysis

Series Aalto University publication series DOCTORAL DISSERTATIONS 250/2017

Field of research Systems and Operations Research

Manuscript submitted 11 September 2017 **Date of the defence** 19 January 2018

Permission to publish granted (date) 9 November 2017 **Language** English

☐ **Monograph** ☒ **Article dissertation** ☐ **Essay dissertation**

Abstract

In practice, behavioral phenomena and procedural aspects are often the most important factors determining the overall success in model based problem solving. Earlier literature has discussed procedural practices and behavioral phenomena such as cognitive biases. However, little attention has been paid to the interdependence between behavioral phenomena and the problem solving process. This Dissertation introduces the idea of path dependence in model based problem solving and in decision analysis, which is a branch of model based problem solving. This idea offers a systemic perspective for capturing the overall impact of cognitive biases and other behavioral phenomena. The term path refers to the sequence of steps taken in the problem solving process. There are usually alternative paths to be followed and the choice of the path can matter. The factors affecting the path include the behavior of the problem solving team, as well as the processes followed, the modeling techniques used, and the problem solving environment, for instance. The idea of paths draws attention to the dynamic interaction of these factors. This Dissertation includes considerations of the effect of the starting point, the accumulation of behavioral effects, and difficulties in changing the path.

Taking the path perspective can support the management of model based problem solving projects. This Dissertation provides a checklist to help the problem solving team to reflect on their path and to be aware of its drivers. Procedures are described to help reduce the risk that the problem solving project gets stuck on a poor path. In decision analysis, the path perspective can help in mitigating the effects of cognitive biases. Biases are a concern especially when their effects build up along the path followed in the decision analysis process. This Dissertation shows that it is sometimes possible to find paths along which the effects of biases cancel out each other. In general, one should try to avoid paths where the effects of biases build up in favor of certain alternatives. This Dissertation introduces new bias mitigation techniques. These techniques are shown to be effective in a decision analysis process.

Portfolio decision analysis is another systemic perspective discussed in this Dissertation. Environmental decisions are often portfolio problems where the task is to find a combination of actions, i.e. a portfolio, to meet the overall objectives. In these decision problems, the traditional approach has been to follow a standard decision analysis process to evaluate alternative portfolios generated manually by experts. This Dissertation describes how biases and path dependence create risks in such processes. The portfolio approach helps avoid these risks and creates new possibilities for stakeholder engagement. This Dissertation presents a review and a synthesis of alternative portfolio modeling approaches. A framework is developed to help environmental modelers use portfolio decision analysis.

Keywords Behavioral operational research, multi-criteria decision making, environmental modelling, portfolio decision making, path dependence, systems perspective, cognitive biases, debiasing

ISBN (printed) 978-952-60-7774-1 **ISBN (pdf)** 978-952-60-7775-8

ISSN-L 1799-4934 **ISSN (printed)** 1799-4934 **ISSN (pdf)** 1799-4942

Location of publisher Helsinki **Location of printing** Helsinki **Year** 2017

Pages 102 **urn** http://urn.fi/URN:ISBN:978-952-60-7775-8

A! Aalto-yliopisto

Aalto-yliopisto, PL 11000, 00076 Aalto www.aalto.fi

Tiivistelmä

Tekijä
Tuomas J. Lahtinen

Väitöskirjan nimi
Malliperusteisen ongelmanratkaisun käytänteiden parantaminen systeemisen käyttäytymisnäkökulman avulla

Julkaisija Perustieteiden korkeakoulu

Yksikkö Matematiikan ja systeemianalyysin laitos

Sarja Aalto University publication series DOCTORAL DISSERTATIONS 250/2017

Tutkimusala Systeemi- ja operaatiotutkimus

Käsikirjoituksen pvm 11.09.2017 **Väitöspäivä** 19.01.2018

Julkaisuluvan myöntämispäivä 09.11.2017 **Kieli** Englanti

☐ **Monografia** ☒ **Artikkeliväitöskirja** ☐ **Esseeväitöskirja**

Tiivistelmä

Malliperusteisessa ongelmanratkaisussa keskeisiä tekijöitä ovat osallistujien toiminta ja heidän seuraamansa prosessit. Aiemmassa kirjallisuudessa on käsitelty prosesseihin liittyviä käytänteitä ja ihmisten käyttäytymiseen liittyviä ilmiöitä kuten kognitiivisia vinoumia. Näiden vuorovaikutukseen ei kuitenkaan ole kiinnitetty juurikaan huomiota. Tässä väitöskirjassa esitellään polkuriippuvuuden käsite malliperusteisen ongelmanratkaisun ja monitavoitteisen päätösanalyysin kentille. Tämä käsite luo systeemisen näkökulman, joka auttaa hahmottamaan kognitiivisten vinoumien ja muiden käyttäytymiseen liittyvien ilmiöiden kokonaisvaikutusta. Polku muodostuu ongelmanratkaisuprosessin vaiheiden tai askelten ketjusta. Vaihtoehtoisia polkuja on yleensä tarjolla, ja polun valinnalla on merkitystä. Mallinnusprojektissa voidaan päätyä eri poluille riippuen muun muassa osallistujien toiminnasta, ongelmanratkaisuympäristöstä, seuratuista prosesseista ja käytetyistä mallinnustekniikoista. Ajatus polusta nostaa esiin dynaamisia ilmiöitä. Tässä työssä pohditaan projektin alussa tehtävien valintojen merkitystä, ihmisen toiminnan vaikutusten kasautumista ja polun vaihtamisen vaikeutta.

Käytännössä polkunäkökulma voi tukea malliperusteista ongelmanratkaisua hyödyntävien projektien hallintaa. Tässä väitöskirjassa esitetään tarkistuslista, joka auttaa polun hahmottamisessa ja polkuun vaikuttavien tekijöiden tunnistamisessa. Lisäksi tässä väitöskirjassa kuvataan tapoja vähentää kehnolle polulle jumiutumisen riskiä. Päätösanalyysissä polkunäkökulma auttaa lieventämään kognitiivisten vinoumien vaikutusta. Vinoumat ovat ongelma erityisesti, jos niiden vaikutukset kasaantuvat. Tässä väitöskirjassa näytetään, että joskus on mahdollista löytää polkuja, joita pitkin kuljettaessa eri vaiheissa syntyvien vinoumien vaikutukset kumoavat toisensa. Yleisesti ottaen tulisi välttää polkuja, joilla vinoumien vaikutukset kasaantuvat joidenkin päätösvaihtoehtojen eduksi. Tässä työssä esitellään uusia tekniikoita vinoumien vaikutusten lieventämiseksi. Nämä osoitetaan toimiviksi eräässä päätösanalyysiprosessissa.

Portfoliopäätösanalyysi on toinen tässä väitöskirjassa käsiteltävä systeeminen näkökulma. Ympäristöä koskevassa päätöksenteossa on usein haasteena muodostaa sopiva toimenpidekokonaisuus, eli portfolio. Perinteistä monitavoitemenetelmää sovellettaessa asiantuntijat luovat vaihtoehtoisia portfolioita ilman portfoliomallien apua. Tässä on riskinä, että ajattelun vinoumat ja polkuriippuvuus muodostuvat ongelmaksi. Tässä väitöskirjassa esitetään kuinka portfoliopäätösanalyysi voi auttaa välttämään nämä riskit, ja kuvataan vaihtoehtoisia tapoja mallintaa portfoliopäätöksiä. Portfoliopäätösanalyysin soveltamisen vaiheista luodaan viitekehys ympäristökysymyksiin erikoistuneiden mallintajien tueksi.

Avainsanat Käyttäytymistutkimuksellinen operaatioanalyysi, monikriteerinen päätöksenteko, ympäristömallinnus, portfoliopäätöksenteko, polkuriippuvuus, systeeminäkökulma, kognitiiviset vinoumat, vinoumien lieventäminen

ISBN (painettu) 978-952-60-7774-1 **ISBN (pdf)** 978-952-60-7775-8

ISSN-L 1799-4934 **ISSN (painettu)** 1799-4934 **ISSN (pdf)** 1799-4942

Julkaisupaikka Helsinki **Painopaikka** Helsinki **Vuosi** 2017

Sivumäärä 102 **urn** http://urn.fi/URN:ISBN:978-952-60-7775-8

Publications

This dissertation consists of a summary and of the following papers.

I. Hämäläinen, R.P., Lahtinen, T.J. 2016. Path Dependence in Operational Research - How the Modeling Process Can Influence the Results. *Operations Research Perspectives,* 3: 14-20.
II. Lahtinen, T.J., Guillaume, J.H.A., Hämäläinen, R.P. 2017. Why Pay Attention to Paths in the Practice of Environmental Modeling? *Environmental Modeling & Software,* 92: 74-81.
III. Lahtinen, T.J., Hämäläinen, R.P. 2016. Path Dependence and Biases in the Even Swaps Decision Analysis Method. *European Journal of Operational Research,* 249(3): 890-898.
IV. Lahtinen, T.J., Hämäläinen, R.P., Jenytin, C. 2017. A Systemic Perspective on Bias Mitigation in Decision Analysis. *Submitted manuscript, 22 pages.*
V. Lahtinen, T.J., Hämäläinen, R.P., Liesiö, J. 2017. Portfolio Decision Analysis Methods in Environmental Decision Making. *Environmental Modeling & Software,* 94: 73-86.

Contributions of the author in the papers

Paper I: Lahtinen and Hämäläinen wrote the text together. Lahtinen assisted Hämäläinen in developing the ideas in the paper. Paper II: Lahtinen was responsible for the main part in writing the text. Lahtinen, Guillaume, and Hämäläinen jointly developed the ideas in the paper. Paper III: Lahtinen was responsible for the main part in writing the text. Lahtinen designed the experiments and analyzed the data. Lahtinen and Hämäläinen collaborated in developing the ideas in the paper. Paper IV: Lahtinen initiated the paper and wrote the text. Hämäläinen provided comments. Lahtinen was the principal designer of the computational analysis. Jenytin did the programming and helped Lahtinen analyze the results. Paper V: Lahtinen was responsible for the main part in writing the text. Hämäläinen initiated the paper. Lahtinen, Hämäläinen, and Liesiö collaborated in developing the ideas in the paper.

Acknowledgements

Many people have influenced this dissertation and my academic path. I am very thankful for all the help, support, and inspiration that I have received.

Raimo, working with you has been very rewarding and fun. I am proud to have been your student and I will forever be grateful for your all-encompassing teaching. Juuso, Joseph, and Cosmo, thank you for the work we did together. Professor Vetschera and Dr. Linkov, thank you for your insightful and encouraging comments in the preliminary examination of this dissertation. Colleagues from the Systems Analysis Laboratory, thank you for our years together. I have been lucky to be around so bright and skilled people. Antti Punkka, thank you for the encouragement at the beginning of my academic journey. Ilkka, Yrjänä, Pekka, Vilma, and Anton, thank you for your companionship along the way. My gratitude goes also to my friends outside of work and to my family. You are an endless source of inspiration, fulfillment, and joy. Tatu, you have been the best friend I can imagine. To my parents I am thankful for the consistent support.

Going through doctoral studies has been great. I have had the opportunity to read, think, discuss, and write in an intellectually stimulating environment. I have begun to see the breadth, the depth, and the value of the knowledge and wisdom that humanity has accumulated over time. This makes me feel both humbled and empowered.

Espoo, 4 December 2017
Tuomas Lahtinen

Contents of the summary

1. Introduction ... 1
2. Background ... 3
  2.1 On Model Based Problem Solving ... 3
  2.2 On Decision Analysis ... 4
3. Contributions of the papers ... 5
  3.1 Path perspective ... 5
  3.2 Contributions by paper ... 7
4. Discussion ... 11
  4.1 Practical implications ... 11
  4.2 Avenues for future research ... 12
References ... 15

1. Introduction

Model based problem solving and decision analysis projects are frequently carried out in government agencies, companies, and other organizations around the world. The application areas range from high stakes environmental decision making to business analytics. Today, advanced software support makes it easier than ever to produce analyses that look convincing and scientific to most people. Yet, success in model based problem solving requires more than just technical and mathematical competence. It is important to understand and be able to manage procedural and behavioral issues as well (Hämäläinen et al. 2013).

Behavioral Operational Research is a new scientific area that aims to improve the practice of model based problem solving by taking into account the behavioral aspects involved (Hämäläinen et al. 2013, Franco and Hämäläinen 2016). So far, these aspects have been studied mainly in decision analysis and in system dynamics (for overviews, see, e.g. French et al. 2009, Sterman 2000), which are subdisciplines of model based problem solving. In decision analysis modelers work directly with preferences and other subjective inputs provided by decision makers and stakeholders. Therefore, natural research questions have been, e.g. how cognitive biases affect these inputs (see, e.g. Clemen 2008), and how to work interactively with stakeholders (see, e.g. Franco and Montibeller 2010). In the general literature on model based problem solving, the importance of behavioral and procedural aspects was acknowledged early (see, e.g. Churchman and Schainblatt 1965, Hildebrandt 1981), but the subsequent interest has been sporadic (Meredith 2001, Franco and Hämäläinen 2016).

This Dissertation takes a systemic perspective to improve the understanding and management of behavioral phenomena in model based problem solving. It is important to pay attention to the overall effects of cognitive biases and other behavioral phenomena. These overall effects result from the interaction of all the factors in the socio-technical system that emerges in the problem solving situation. This system consists of the members of the problem solving team, the processes followed, the techniques used, the problem context, and the external environment, for instance. In the earlier literature, little attention has been paid to the interdependence between behavioral phenomena and the problem solving process.

This Dissertation aims to i) improve the planning and management of model based problem solving projects (Papers I and II), ii) help mitigate biases in decision analysis processes (Papers III and IV), and iii) support environmental decision makers in utilizing portfolio methods (Paper V).

Paper I introduces the concept of path dependence in model based problem solving. In practice, the results of a modeling process can depend on the path followed. Alternative paths are almost always available. This paper studies the drivers and implications of path dependence on different scales.

Paper II describes how the path perspective can help to improve the planning and management of model based problem solving projects. This paper draws examples from environmental modeling, where a typical problem is participatory and includes multiple sources of uncertainties. These factors increase the need to reflect on the path taken.

Paper III presents a behavioral experiment that demonstrates the existence of biases and path dependence in a decision analysis process. This paper also describes how biases can create path dependence in decision analysis in general.

Paper IV is focused on ways to mitigate cognitive biases in decision analysis. This paper presents four bias mitigation techniques and evaluates them computationally.

Paper V describes how environmental modelers can benefit from using portfolio decision analysis methods. This paper presents a synthesis and a review of portfolio modeling approaches and a framework for using portfolio decision analysis.

2. Background

2.1 On Model Based Problem Solving

"A model is an abstract description of the real world; it is a simple representation of more complex forms, processes, and functions of physical phenomena or ideas" (Rubinstein 1975). Modeling can support problem solving in various ways. For instance, models can help to generate alternatives or solution candidates, to evaluate alternative policies or systems, and to automate routine decision making (see, e.g. Brill et al. 1982, Pidd 1999). In general, developing and using models can help to organize one's thinking and to increase understanding of the situation under study (see, e.g. Rubinstein 1975).

Traditionally, a model based problem solving process is seen to consist of stages (see, e.g. Churchman et al. 1957). Typical stages include: 1. Defining the situation under study, e.g. identifying objectives and the scope of the problem. 2. Developing models, e.g. specifying the assumptions used and the key variables. 3. Data collection, estimation of the magnitudes of parameter values, and the elicitation of preferences. 4. Solving the models. 5. Evaluating and using the models, e.g. comparing results against data or expert judgment, performing sensitivity and what-if analyses. 6. Using results of the models to inform the decision makers and communicating the insights to stakeholders. These stages are not always carried out in the same order and one can iterate between them.

In practice, there are almost always many plausible and justifiable ways to carry out each stage in the modeling process. Choices made by the problem solving team drive the progression through the stages (Hämäläinen et al. 2013). Therefore, it is not surprising that different problem solving teams can obtain different results when the same problem is given to them (see, e.g. Mulvey 1979, Richels 1981, Linkov and Burmistrov 2003). Members of the problem solving team typically include modelers, subject matter experts, problem owners, and stakeholders.

2.2 On Decision Analysis

Decision analysis is a subdiscipline of model based problem solving. Technically, decision analysis aims to help decision makers evaluate alternatives in the face of multiple conflicting objectives and uncertainties (see, e.g. Keeney and Raiffa 1976). In practice, increased insight is often the overall goal in decision analysis processes (see, e.g. Howard 1980, Keeney 1982). The benefits may also include, for instance, improved communication, greater transparency, and the identification of the conflicting views among the stakeholders.

The decision analysis process aims to comprehensively identify, explicate, and analyze the facts and values that are relevant to the decision problem at hand. A typical process includes the following stages (see, e.g. Keeney 1982). 1. Identifying the objectives of the decision makers and stakeholders. 2. Developing alternative courses of action. 3. Determining attributes for measuring the achievement of the objectives. 4. Estimating the consequences of the alternatives in the attributes. 5. Eliciting the decision maker's preferences and developing value models for evaluating the alternatives. 6. Analyzing the performances of the alternatives and conducting sensitivity analyses. There are usually different ways to carry out each of these stages. Revisiting earlier stages is also possible. In portfolio decision making, the problem is to find a combination of actions with desirable overall consequences (see, e.g. Salo et al. 2011). Then additional stages are needed in the decision process in order to identify and model interactions across the set of action candidates, to develop models to calculate the overall consequences of alternative portfolios, to to specify the problem constraints, and to identify non-dominated portfolios by using optimization techniques.

The Even Swaps process (Hammond et al. 1998) is one approach to help the decision maker identify her most preferred alternative. This process can be carried out after the decision alternatives have been specified and their consequences have been estimated in the attributes. In the Even Swaps process the decision maker's preferences are not captured with a value model as in a typical decision analysis process. Instead, the decision maker performs a sequence of even swap tasks. In these tasks, the decision maker modifies an alternative in two attributes in order to create a preferentially equivalent hypothetical alternative. The goal is to create situations where a modified alternative either dominates, or is dominated by, another alternative. Even swap tasks are carried out until only one alternative remains non-dominated.

An important practical issue in decision analysis is coping with cognitive biases when preferences and other subjective inputs are elicited from decision makers and stakeholders. There have been many suggestions on how to mitigate the effects of biases (see, e.g. Montibeller and von Winterfeldt 2015). However, the number of studies analyzing the effectiveness of these suggestions remains very limited.

3. Contributions of the papers

3.1 Path perspective

Papers I and III introduce the concept of path dependence in model based problem solving and in decision analysis, respectively. Paper II describes how taking the path perspective can support the management of model based problem solving and decision making projects. Paper IV uses the path perspective in the mitigation of biases in decision analysis. Paper V describes how path dependence can create risks in a decision making approach used traditionally in environmental portfolio problems.

The term path refers to the sequence of steps taken in the problem solving process, or alternatively to the trajectory describing how a problem solving project develops over time. In the practice of model based problem solving, there are usually alternative paths to be followed and the choice of the path can matter. Path dependence is an integrative concept because it draws attention to all the factors that shape the path. These factors can relate to the behavior of the problem solving team, as well as the processes followed, the modeling techniques used, and the problem solving environment, for instance. The path perspective emphasizes the sequential nature and dynamics of modeling processes. Examples include the effect of the starting point (see, e.g. Papers I, II and V), the accumulation of behavioral effects along the path (see, e.g. Papers III and IV), and that changing the path at an intermediate step can be difficult (see, e.g. Paper II).

Path dependence is not a risk as such. In most cases, there are likely to be different paths that can lead to useful outcomes. However, a risk emerges from the possibility that a modeling process may follow and get stuck on a poor path. Optimistically, one may think that mistakes along the path are usually easy to notice and correct. Papers I and II explain why this might not be the case. A modeling process can get stuck on a certain path, for example, due to budget and time constraints, hidden motives, cognitive biases such as anchoring (Tversky and Kahneman 1974) and confirmation bias (Nickerson 1998), and also due to a social environment that causes people to hold back critical opinions on the path taken (see, e.g. Janis 1982).

Paths discussed in this Dissertation:

- Paths in modeling and decision analysis projects in general. A starting point of such a path can be the initial meeting between modelers and problem owners. The end of the path can be, e.g., the point when a final report is delivered, or when problem owners have decided on a course of action. However, clear starting and ending points do not necessarily exist.
- Paths in preference elicitation processes. A path consists of the sequence of preference elicitation tasks carried out by the decision maker.
- Paths in the Even Swaps process. A path consists of a sequence of even swap tasks carried out by the decision maker.

- Paths in the generation of portfolios without modeling support. A path is the order in which different actions are considered and added into the portfolio.
- “Historical” paths in the development of research communities, organizations, etc. These paths relate to general trends such as the popularity of methods, ideas and research topics.

The last item relates closely to the concept of path dependence discussed in economics (David 1985, Arthur 1989) and organizational decision making (Sydow et al. 2009), for instance.

3.2 Contributions by paper

A summary of the contributions of each paper is provided in Table 1.

Paper I describes how path dependence can emerge in model based problem solving processes in general. In modeling, the path is driven by systemic phenomena, learning, the procedures used, behavioral and motivational phenomena, uncertainties, and the external environment. The awareness and understanding of these drivers can help modelers to manage their problem solving processes better. This paper describes several mechanisms, which may cause a problem solving team to become anchored to their initial approach. Procedures to cope with path dependence are identified and discussed. These include starting the modeling process by carefully exploring the goals and objectives of the stakeholders, openness to multiple approaches, creating multiple parallel modeling processes, and adaptive problem solving.

Paper II clarifies why and how to pay attention to paths in model based problem solving projects. This paper draws examples from environmental modeling, but the conclusions are applicable to model based problem solving in general. This paper elucidates how the path perspective can i) help plan and manage modeling projects, ii) help communicate about the practice of modeling, and iii) provide a lens for understanding the role of behavioral effects in modeling. This paper develops a framework, which is intended to help modelers reflect on their paths. The framework classifies path related phenomena based on their origins and their possible effect. These phenomena may affect choices at the forks on the path, give a reason to redirect the path, and make it difficult to change the path taken. This paper also develops a checklist for the practitioner. This checklist supports detecting forks, evaluating alternative paths, and recognizing situations where changing the path may be desirable.

Paper III shows that decision analysis processes can be path dependent. A major reason is that the impact of cognitive biases can depend on the path followed. On some paths, the effects of biases may accumulate or build up such that one alternative becomes favored in the decision process. It is also possible that the effects of biases cancel out each other. This paper presents a behavioral experiment that shows the existence of path dependence in the Even Swaps process (Hammond et al. 1998). This is explained by the accumulated effect of two well known cognitive biases. These are the loss aversion bias (Tversky and Kahneman 1991) and the measuring stick bias, which is also called the scale compatibility bias (Tversky et al. 1988, Delquié 1993). This paper suggests ways to mitigate the effects of these biases.

Paper IV develops and evaluates techniques for bias mitigation in decision analysis. These techniques are based on the ideas introduced in Paper III. The basic idea is to look for paths where the overall effect of biases is minimal. The first new technique is to introduce a virtual reference alternative in the decision problem. The second one is to introduce a virtual measuring stick attribute. The third approach is to rotate the reference point used. The fourth one is the intermediate restarting of the process in order to eliminate the impacts of biases that have accumulated during the earlier steps. A computational analysis demonstrates that these techniques help to mitigate biases in the Even Swaps decision analysis process. It is described how these techniques could be used with other decision analysis processes as well. This paper demonstrates that a computational approach helps to take a systemic perspective on debiasing. In particular, this approach enables assessing the overall effect of multiple biases that occur on different steps along the decision making process. Earlier literature has mostly considered the effects of biases in isolated steps of the decision analysis process.

Paper V reviews portfolio modeling approaches and provides a framework to help environmental modelers use portfolio decision analysis in practice. An illustrative case dealing with an environmental decision is presented. This case is analyzed using a portfolio decision analysis method called Robust Portfolio Modeling (Liesiö et al. 2007). In environmental portfolio problems, the traditional approach has been to follow a standard decision analysis process to evaluate alternative portfolios generated by experts without modeling or optimization support. This paper describes how biases and path dependence create risks in such an approach. Furthermore, when the traditional approach is used, it can be impossible to consider all combinations of actions even in moderate sized problems (e.g. 10 action candidates), because the number of combinations is too high. Portfolio modeling alleviates these concerns because all action candidates can be included simultaneously in the same analysis. Use of portfolio decision analysis also creates new possibilities for stakeholder engagement. The participants of the process can easily suggest actions to be included in the same analysis together with all the other action candidates. This can help create a sense of shared ownership of the process.

Table 1: Summary of the papers.

	Contexts	Main objectives	Main results
I	Model based problem solving in general.	To demonstrate the existence of path dependence and to describe its origins.	Path dependence can originate from systemic phenomena, learning, procedure, behavior, motivation, uncertainty, and external environment. There are procedures for coping with path dependence.
II	Model based problem solving projects. Environmental modeling.	To describe how the path perspective can help to improve the practice of model based problem solving.	Taking the path perspective can help modelers to navigate their paths in a reflective mode. A checklist for planning and managing modeling projects.
III	Decision analysis processes. The Even Swaps process.	To study path dependence experimentally in a decision analysis process.	Path dependence exists in the Even Swaps process. This can be explained by the accumulated effect of the loss aversion and the measuring stick biases.
IV	Decision analysis processes. The Even Swaps process.	To develop bias mitigation techniques and to evaluate them computationally.	New bias mitigation techniques are effective. The computational approach helps assess the overall impact of biases.
V	Portfolio decision analysis processes. Environmental decision making.	To help environmental modelers to use portfolio decision analysis.	Portfolio decision analysis offers new possibilities for environmental decision making. A framework for using portfolio decision analysis.

4. Discussion

4.1 Practical implications

This Dissertation helps to understand the impact of behavioral phenomena in model based problem solving. In practice, behavioral phenomena and procedural aspects are often the most important factors determining the overall success in model based problem solving. Participatory environmental problem solving is one application area where these factors are particularly important.

The notion of path dependence helps to acknowledge that alternative paths are usually available in model based problem solving and that the choice of path can matter. Increased understanding of path related phenomena can improve one's ability to identify and evaluate alternative paths. The path perspective can be useful for anyone working with model based problem solving. In modeling projects, reflecting on the path and its drivers can help to notice forks on the path and to redirect the path if needed. Practitioners may find interest in the procedures to cope with path dependence described in Paper I, and in the framework and in the checklist developed in Paper II.

In decision analysis, an important practical issue is to mitigate biases in the subjective inputs elicited from stakeholders. Papers III and IV show that in the mitigation of biases it can be useful to consider the entire path followed in the decision analysis process. It may be possible to find paths along which the effects of biases cancel out each other. In general, one should at least try avoid situations where the effects of biases build up in favor of a certain alternative. Paper IV describes techniques, which are shown to be effective at mitigating cognitive biases in the Even Swaps process. These techniques are likely to be applicable also with other decision analysis methods, such as swing and trade-off methods for the elicitation of attribute weights.

Environmental decisions are often portfolio problems, where a combination of actions is needed to create a successful management policy. Paper V describes tools and provides a framework to help environmental managers and modelers address such problems. The framework includes the most important steps and tasks needed to analyze a portfolio decision problem.

4.2 Avenues for future research

The idea of path dependence can be seen as an integrative perspective in Behavioral Operational Research. When studying cognitive biases and other behavioral phenomena in model based problem solving, it is important to pay attention to their overall effects. The overall effects result from the interaction of all the factors in the problem solving process.

This Dissertation provides several directions for future research on the management of modeling projects. It could be evaluated how to best take the path perspective into account already when commissioning a modelling project. Moreover, the idea of parallel modeling teams should be tested in practice and developed further. One question that is likely to arise in practice is how to compare the results obtained by different teams. Another interesting topic would be to study how the principles of systems intelligent leadership (Saarinen and Hämäläinen 2004) might help to manage modeling projects and to work interactively with stakeholders. The path perspective relates closely to five dimensions of systems intelligence (Törmänen et al. 2016). These are systems perception, reflection, spirited discovery, wise action, and effective responsiveness.

In decision analysis, a systemic perspective is needed when assessing the effects of cognitive biases and evaluating bias mitigation methods. Earlier literature has identified a number of biases. However, these have been analyzed mostly in isolated steps of the decision analysis process. This Dissertation shows that one should also consider the possibility that the effects of biases build up or accumulate. The effects of biases may also interact with each other. A computational approach could be more generally used for supporting the design and evaluation of new bias mitigation methods.

In environmental decision making, the portfolio approach should be tested in practice. This is likely to evoke a number of interesting research questions. For example, procedures for creating the portfolio model interactively with stakeholders are likely to be needed. It might also be useful to develop better tools for supporting situations with strong non-linearities or a high number of interactions across the set of actions.

This Dissertation identifies a number of behavioral phenomena that can influence the problem solving path, as well as phenomena that can emerge due to the path followed. A natural theme for future research is to consider these phenomena in more detail and in different contexts. Paying attention to behavioral effects is important particularly when using models to support high stakes policy decision making, such as the development of climate policies. Greater understanding of behavioral phenomena is likely to increase transparency of model based problem solving and to help run modeling projects more successfully.

References

Arthur, W.B. (1989). Competing technologies, increasing returns, and lock-in by historical events. The Economic Journal, 99(394), 116-131.

Brill Jr, E. D., Chang, S. Y., and Hopkins, L. D. (1982). Modeling to generate alternatives: The HSJ approach and an illustration using a problem in land use planning. Management Science, 28(3), 221-235.

Churchman, C. W., Ackoff, R. L., & Arnoff, E. L. (1957). Introduction to operations research. John Wiley & Sons.

Churchman, C.W., and Schainblatt, A.H. (1965). The Researcher and the Manager: A Dialectic of Implementation. Management Science, 11(4), B69-B87

Clemen, R. T. (2008). Improving and measuring the effectiveness of decision analysis: Linking decision analysis and behavioral decision research. In: Kugler, T., et al. (Eds.) Decision modeling and behavior in complex and uncertain environments. Springer New York, 3-31.

David, P.A. (1985). Clio and the Economics of QWERTY. The American Economic Review, 75(2), 332-337.

French, S., Maule, J., Papamichail, N. (2009). Decision behaviour, analysis and support. Cambridge University Press, Cambridge.

Franco, L. A., and Montibeller, G. (2010). Facilitated modelling in operational research. European Journal of Operational Research, 205(3), 489-500.

Franco, L. A., and Hämäläinen, R. P. (2016). Behavioural operational research: Returning to the roots of the OR profession. European Journal of Operational Research, 249(3), 791-795.

Hammond, J. S., Keeney, R. L., and Raiffa, H. (1998). Even swaps: A rational method for making trade-offs. Harvard Business Review, 76, 137-150.

Hildebrandt, S. (1981). Implementation—the bottleneck of operations research: the state of the art. European Journal of Operational Research 6(1), 4-12.

Howard, R. A. (1980). An assessment of decision analysis. Operations Research, 28(1), 4-27.

Hämäläinen, R.P., Luoma, J., and Saarinen, E. (2013). On the Importance of Behavioral Operational Research: The Case of Understanding and Communicating about Dynamic Systems. European Journal of Operational Research, 228(3), 623-634.

Janis, I.L. (1982). Groupthink: psychological studies of policy decisions and fiascoes. Wadsworth.

Keeney, R.L., and Raiffa, H. (1976). Decisions with Multiple objectives: Preferences and value trade-offs. John Wiley & Sons, New York.

Keeney, R. L. (1982). Decision analysis: an overview. Operations Research, 30(5), 803-838.

Liesiö, J., Mild, P., and Salo, A. (2007). Preference programming for robust portfolio modeling and project selection. European Journal of Operational Research, 181(3), 1488-1505.

Linkov, I., and Burmistrov, D. (2003). Model uncertainty and choices made by modelers: Lessons learned from the international atomic energy agency model intercomparisons. Risk Analysis, 23(6), 1297-1308.

Meredith, J. R. (2001). Reconsidering the philosophical basis of OR/MS. Operations Research, 49(3), 325-333.

Montibeller, G., and von Winterfeldt, D. (2015). Cognitive and motivational biases in decision and risk analysis. Risk Analysis, 35(7), 1230-1251.

Mulvey, J. M. (1979). Strategies in modeling: A personnel scheduling example. Interfaces, 9(3), 66-77.

Nickerson, R.S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. Review of General Psychology, 2(2), 175-220.

Pidd, M. (1999) Just Modeling Through: A Rough Guide to Modeling. Interfaces, 29(2), 118-132.

Richels, R. (1981). Building good models is not enough. Interfaces, 11(4), 48-54.

Rubinstein, M. F. (1975). Patterns of Problem Solving. Prentice-Hall.

Saarinen, E., and Hämäläinen, R. P. (2004). Systems intelligence: Connecting engineering thinking with human sensitivity. In: Raimo P. Hämäläinen and Esa Saarinen (Eds.). Systems Intelligence – Discovering a Hidden Competence in Human Action and Organizational Life, Helsinki University of Technology: Systems Analysis Laboratory Research Reports, A88.

Salo, A., Keisler, J.M., and Morton, A., (2011). Portfolio Decision Analysis. Springer.

Sterman, J. D. (2000). Business dynamics: Systems thinking and modeling for a complex world. Boston: McGraw-Hill.

Sydow, J., Schreyögg, G., and Koch, J. (2009). Organizational Path Dependence: Opening the Black Box. Academy of Management Review, 34(4), 689-709.

Tversky, A., and Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. Science, 185, 1124-1131.

Tversky, A., and Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model**.** Quarterly Journal of Economics, 106(4), 1039-1061.

Tversky A., Sattath S., and Slovic P. (1988). Contingent weighting in judgment and choice**.** Psychological Review, 94(3), 371-38

Törmänen, J., Hämäläinen, R. P., and Saarinen, E. (2016). Systems intelligence inventory. The Learning Organization, 23(4), 218-231

Aalto-DD 250/2017

ISBN 978-952-60-7774-1 (printed)
ISBN 978-952-60-7775-8 (pdf)
ISSN-L 1799-4934
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

Aalto University
School of Science
Department of Mathematics and Systems Analysis
www.aalto.fi

BUSINESS +
ECONOMY

ART +
DESIGN +
ARCHITECTURE

SCIENCE +
TECHNOLOGY

CROSSOVER

DOCTORAL DISSERTATIONS