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Path dependence in Operational Research—How the modeling process can influence the results

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HIGHLIGHTS

- The results of modeling process can depend on the problem solving path.
- Awareness of the possibility of path dependence is important in OR.
- The drivers are: system, learning, procedure, behavior, motivation, uncertainty and context.
- Sociopsychological dynamics create a system in participative problem solving.
- Ways to cope with path dependence are discussed.

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ABSTRACT

In Operational Research practice there are almost always alternative paths that can be followed in the modeling and problem solving process. Path dependence refers to the impact of the path on the outcome of the process. The steps of the path include, e.g. forming the problem solving team, the framing and structuring of the problem, the choice of model, the order in which the different parts of the model are specified and solved, and the way in which data or preferences are collected. We identify and discuss seven possibly interacting origins or drivers of path dependence: systemic origins, learning, procedure, behavior, motivation, uncertainty, and external environment. We provide several ideas on how to cope with path dependence.

1. Introduction

Path dependence is a concept which has been widely used in different areas including economics [1–3], policy studies [4,5], ecology [6,7], complex adaptive systems [8,9], sociology [10–12], political science [13], and organizational decision making [14]. The general idea is that 'history matters', i.e. the current state of the world depends on the path taken to reach it. The concept also often refers to the lock-in phenomenon: the development of strong anchor points from which it is not easy to move forward. The most famous example is the QWERTY layout which has become the worldwide standard for keyboards [1].

We have earlier discussed path dependence in decision analysis [15] and in this paper we want to bring path dependence into focus also in modeling and Operational Research (OR) in general. We see that the topic is of both theoretical and practical interest in model supported problem solving and decision making. A path is the sequence of steps that is taken in the modeling or problem solving process. The steps can include, for example, the initial meeting between the problem owners and modelers, formation of the problem solving team, the framing and structuring of the problem, the choice of model, the order in which different parts of the model are specified and solved, the way in which data or information about preferences are collected, communication with the model, as well as the implementation of the results in policy and practice. Earlier research on path dependence in other disciplines has focused on exposing and describing it. In OR we also want to find ways to mitigate the risks related to it. Behavioral and social effects are likely to be the most important drivers of path dependence in OR. We see path dependence as an important topic in the emerging area of Behavioral Operational Research (BOR) [16]. Although the focus of this paper is mainly in OR, we believe that the ideas and the phenomena described in this paper are relevant in policy analysis, systems analysis, and generally in all model supported problem solving approaches.

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Table 1
Summary of origins and drivers of path dependence.

Origin or driver	Relates to	Brief explanation
System	Interactions between participants of the problem solving team, related organizations, stakeholders, and the system under study.	Social dynamics influence the modeling process. Technical properties related to the problem or the system under study can also result in path dependence.
Learning	Learning during the OR process.	Increased understanding about the problem and methods used can direct the modeling and problem solving process.
Procedure	Structure and properties of the models, algorithms and problem solving procedures used.	Different procedures can lead the OR process to different outcomes. Structures and properties of the methods used interact with the other drivers of path dependence.
Behavior	Cognitive biases and behavioral phenomena related to individuals.	These phenomena can occur in different steps and their overall effect depends on the path followed.
Motivation	Exposed and hidden goals.	People can promote their own interest and behave strategically in the OR process.
Uncertainty	Uncertainty about structural assumptions and correct parameter values.	Different structural assumptions can lead us to consider different models. Results usually depend on the parameter values chosen.
External environment	Context and external environment.	The problem environment can change so that the chosen modeling process becomes invalid or it can lead to a different outcome.

There are usually alternative ways of using models to support problem solving. The possibility that different 'valid' modeling paths lead to different outcomes was acknowledged already early by Landry et al. [17] but the topic has received little interest later in the OR literature. Path dependence is implicitly recognized in the papers on best practices in OR as this literature recognizes the possibility of following different practices (see, e.g. [18–21]). Little [22] and Walker et al. [23] have suggested that models should be adaptively adjusted as the process evolves and intermediate results are obtained. This naturally results in one form of path dependence as the model outcomes change in response to changes in the model. Also the literature on the ethics of modeling discusses how the modeling process matters [24,25]. These papers clearly acknowledge that the process can influence the results in model supported problem solving. Still, research on the drivers and consequences of path dependence in different modeling contexts remains scattered and very limited. We see that the term path dependence is useful as an integrative term referring to the different phenomena that originate from the modeling and problem solving process and influence its outcome.

The ideal situation in OR is that we have a model and a solution procedure which produces one optimal solution. In OR practice, the risk of path dependence still exists. Awareness of path dependence and its possible consequences is important especially in major policy problems in areas such as environmental management [26] and in long term policy analyses involving deep uncertainties [27]. Yet, when the main goals of the process are related to learning and creation of a common view about the problem situation, then path dependence might not only be a negative phenomenon. Working through the process along different paths with different outcomes can sometimes be useful. It can show the sensitivity of the solution and that a model can give rise to different conclusions.

This paper studies the origins and drivers of path dependence in model supported problem solving. We also discuss possible ways to cope with path dependence in practice. We identify seven types of origins for path dependence: systemic, learning, procedure, behavior, motivation, uncertainty and external origins. These possibly interacting drivers and origins relate to humans, technical systems, as well as the problem context. In practice, the listing or categorization of the drivers and origins is not a goal in itself but it is important to try to consider all possible causes of path dependence.

2. Origins and drivers of path dependence

In the following, we describe the seven drivers and origins of path dependence. These can interact and occur together. A summary is provided in Table 1.

2.1. Systemic origins

Systemic origins of path dependence relate to the social system formed by the interaction of people involved in the problem solving process, the organizations related to the process, the stakeholders, and the system under study.

Groupthink, studied by Janis [28], is a social phenomenon which can occur in cohesive modeling communities of practice. Members of a problem solving team can convince each other of the correctness of the approach designed by the team without critical thinking or consideration of alternative approaches. According to Janis [28] groupthink is more likely to occur if the group is insulated, the background of the group members is homogeneous, and also if there is high stress due to external threats. In the OR context the team members can all have their background in the same modeling community dedicated to the use of a particular approach. External threat could be created for example by competing modeling teams or result from time constraints to complete the project.

A related human trait is the need for closure, which has been studied in model based group decision making by Franco et al. [29]. A group with high need for closure wants the problem solving process to end up in an unambiguous uncontested outcome. Once the first clear solution candidate has been obtained, the group members can start to endorse this solution and refrain from further deliberation.

The way in which the modelers initially interact with the participants in the social setting can greatly influence the results in participatory modeling processes [30]. Mehrotra and Grossman [31] provide an example where trust earned from the frontline workers of the client organization was essential for successful communication and problem identification. Social phenomena which occur in groups also include the contagion of emotions. This phenomenon can naturally play a role when the people engaged in the modeling process meet and communicate with each other. Contagion of positive mood has been found to increase cooperation and decrease conflicts in group problem solving [32]. Yet, contagion of positive mood does not necessarily improve the modeling process as elevated positivity can reduce critical thinking and cause groupthink [32].

In practice it can often be impossible to undo the steps taken and restart the modeling process again once one path is initiated. A lock-in to one approach and one software can emerge when the problem solving team and the organization become more and more involved and have invested time and resources in the process. This is a problematic situation if there are new, better, approaches available but the organization keeps on using the old one. The sunk cost effect can sometimes explain the lock-in situation but it can