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GRAPPLING WITH UNCERTAINTY IN THE LONG-TERM DEVELOPMENT OF INFRASTRUCTURE SYSTEMS

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ABSTRACT

Infrastructure systems are crucial to the functioning of society. Their long-term planning is therefore of great importance. The uncertainties about the future encountered in the long term planning of infrastructure systems is increasing. Despite the increasing uncertainty, planning is still based on the out-dated assumption that the future can be predicted accurately enough for static planning. We review the state of the art of an alternative planning paradigm that starts from the explicit recognition of the inability of forecasting and the need for adaptivity and flexibility. In light of the review, we present a research agenda identifying four areas of research.

KEYWORDS

Uncertainty, infrastructure planning, dynamic adaptive policymaking

INTRODUCTION

Infrastructure systems are crucial to modern societies. They shape and are shaped by various economic, social, cultural, and technological developments. Given this importance, their long-term development is of primary concern. For efficacious long-term planning uncertainty about the future is a key challenge. Uncertainty has arguably increased since many infrastructure systems have witnessed a change in ownership structure and market structure due to privatization and liberalization over the past years. These changes have created new dynamics, altered the perception of the general public, and affected the key criteria that are used in long-term planning. Moreover, we observe an increased interconnectedness between various infrastructures, given rise to all sorts of unanticipated effects. A clear example of this is the way in which a problem related to the financing of housing in some parts of the United States has given rise to a global economic recession.

Despite the changes that various infrastructure systems have witnessed in the past decennium, the ways in which the long-term development is planned appeared to have not changed that much. Confronted by the problems of uncertainty in the form of the economic downturn and climate change, infrastructure planners need to reconsider how they plan the long-term development of the infrastructure. In this paper, we review the various ways in which in general uncertainty can be handled in infrastructure planning, review the state of the art on new approaches that have been suggested in light of the problems posed by uncertainty, and outline a research agenda for research into these new approaches bases on the key research challenges that have been identified.

UNCERTAINTY IN THE LONG-TERM DEVELOPMENT OF INFRASTRUCTURES

Deep uncertainties about the future pose a significant challenge to infrastructure planning. Decision making under deep uncertainty is understood as the situation in which the decisionmaker does not know, or multiple decisionmakers cannot agree on, the system model, the prior probabilities for the uncertain parameters of the system model and/or the value function. To cope with uncertainties in the long-term development of infrastructure three basic approaches are possible:

- Predict the worst case and design the system so that it can maintain functioning under these conditions
- Assess a range of possible conditions and design the system to maintain an reasonable functioning across this range
- Design the system so that it can adapt to a wide range of imaginable conditions.

The first two approaches have long dominated in infrastructure planning (Quade 1982; Dempsey, Goetz et al. 1997; McDaniel and Driebe 2005; Van Geenhuizen, Reggiani et al. 2007; van Geenhuizen and Thissen 2007; Marchau, Walker et al. 2009). Planners extrapolated past trends forward and developed static blueprint plans for achieving the desired goals. However, both these approaches suffer from the same fundamental defect: forecasts, whether point forecasts or forecasts of ranges are practically always wrong in that the future that materializes differs significantly from the forecasted future (Ascher 1978; Porter, Roper et al. 1991; Flyvbjerg, Bruzelius et al. 2003). Moreover, both approaches suffer from the problem that they focus on those uncertainties that are "among the least of our worries; their effects are swamped by uncertainties about the state of the world and human factors for which we know absolutely nothing about probability distributions and little more about the possible outcomes" (Quade 1982). Similarly, Goodwin and Wright (2010p. 355) demonstrate that "all the extant forecasting methods – including the use of expert judgment, statistical forecasting, Delphi and prediction markets – contain fundamental weaknesses." And Popper, et al. (2009) state that the traditional methods "all founder on the same shoals: an inability to grapple with the long-term's multiplicity of plausible futures." Any plan designed on the basis of one or a few forecasts and a narrow set of assumptions about the future performs poorly as a result and unplanned ad-hoc modifications of and deviation from the plan are needed to rectify this.

In response to the deficiencies of traditional planning, the third approach has emerged. This approach holds that, in light of the deep uncertainties, one needs to plan dynamically and build in flexibility (de Neufville 2000; Walker, Rahman et al. 2001; Lempert 2002; Albrechts 2004; IISD 2006; Lempert and Groves 2010; Swanson, Barg et al. 2010). According to this approach, the solution to planning under uncertainty is to create a shared strategic vision of the future, commit to short-term actions, and establish a framework to guide future actions. (Walker, Rahman et al. 2001; Albrechts 2004). A plan that embodies these ideas allows for

the dynamic adaptation of the plan over time to meet the changing circumstances. This planning paradigm, in one form or another, has been receiving increasing attention in various disciplines. In infrastructure planning, the need for adaptivity and flexibility is increasingly recognized. For example, in air transport, the developments of the last decade, including various terrorist attacks, SARS, Mexican flu, and the second Gulf war, have highlighted this need. Combine this with the impacts of privatization and liberalization, the rise of airline alliances, mergers, and take-overs, and the emergence of new players in the industry, such as low cost carriers, and it is obvious that it is next to impossible to plan for the long-term development of an airport based on a prediction of the size and composition of future demand. In response to these uncertainties, the need for dynamic adaptive planning has been forcefully argued (de Neufville 2000; Walker, Rahman et al. 2001; de Neufville and Odoni 2003; Burghouwt 2007; Kwakkel, Walker et al. 2010). Another argument for dynamic adaptation in the transport domain comes from research on transport innovations. The implementation of innovations, such as advanced driver assistance systems and innovative approaches for intra-city logistics, is hampered by a variety of uncertainties, including uncertainties about the technology to be implemented and about the future structure of the transport system itself. Dynamic flexible implementation plans have been put forward as a way to overcome these problems (Marchau and Walker 2003; Marchau, Walker et al. 2009). In other domains, the need for adaptivity and flexibility is argued on very similar grounds. For example, in integrated river basin management, the omnipresence of uncertainties in both the environmental system and the societal system is used as an argument for adaptivity and flexibility (Pahl-Wostl, Moltgen et al. 2005; Pahl-Wostl, Sendzimir et al. 2007). Policymaking with respect to climate change is yet another area in which dynamic adaptation and flexibility are suggested as the appropriate approach for policy design (Dessai, Hulme et al. 2009; Wardekker, de Jong et al. 2010).

OUTLINE OF A RESEARCH AGENDA

In light of the irreducible problems of uncertainty for planning the long-term development of infrastructure, DAP appears to be a most promising approach. In light of the state of the art, we identify four key research challenges. First, in the DAP literature, adaptive policies are presented primarily for clarification. These adaptive policies are developed in an ad hoc manner and represent the expert opinion of the authors of the papers. For adaptive policymaking to become a useful planning approach, the first research challenge is to specify in more depth how the various steps can be carried out and which methods and techniques can be employed in each of the steps. That is, adaptive policymaking needs to move from being a high level concept captures in a single framework, to being a detailed planning approach. It is believed that many of the available techniques, such as forecasting, scenarios, and Exploratory Modeling and Analysis can be of great use in the various steps of adaptive policymaking. However, exactly how these techniques can be employed for the purpose of developing and adaptive policy needs to be researched.

The second research challenge focuses on the institutional and decisionmaking implications of Dynamic Adaptive Policymaking. The latter focuses on the problem of how to agree on an adaptive policy. On the one hand, agreement might be facilitated by DAP for it reduces uncertainties about future outcomes. On the other hand, it is uncertain upfront which parts of the adaptive policy will be implemented. So, adaptive policies reduce outcome uncertainties, but create new uncertainties about what will be implemented. Moreover, given that the policy is not implemented at the start in its entirety, there is the possibility of renegotiation in the future. To overcome this uncertainty, the institutional arrangements and safeguards with

respect to the monitoring system and the triggering of future actions is a key research challenge. Only if there are institutional arrangements in place that safeguard the execution of triggers, this problem can be overcome. A related institutional problem is that it has been argued that most institutions, particularly governmental ones, have a limited ability to cope with deep uncertainty. A simple example of this is the often heard complaint that governments do not look beyond the next election. Yet another institutional problem is that he implementation of adaptation can be hindered by several institutional and social complexities, such as too many policy domains, too many administrative levels, too fragmented and rigid regulation and budgets, too detailed planning and budget allocation procedures, lack of awareness, insufficient learning capacity of key players, etc. "Today's policymakers generally lack the tools and the institutions that can … identify priority long-term decisions" (Lempert and Light 2009). For the successful application of Dynamic Adaptive Policymaking, the institutional arrangements that are necessary for Adaptive Plans to be decided on and implemented are a key research topic.

A third research challenge is assessing the efficacy of DAP in comparison to tradition policymaking. The reviewed literature has identified a few papers that provide computational evidence from a single case for its efficacy. More research on this is needed. The presented medical analogy can guide this effort. Most importantly, next to computational evidence, additional sources of evidence such as in vitro experimentation using simulation gaming need to be exploited. Most importantly, addressing this research challenge will help in improving the validity of Dynamic Adaptive Policymaking. But as a beneficial spin-off the accumulated evidence can also be used to convince decisionmakers and stakeholders that they should adopt DAP as their main way of doing long-term planning.

A final research challenge is the assessment of the costs and benefits of adaptive policies in comparison to tradition policies. Cost benefit analysis is used for many decisionmaking problems to support decisionmaking. Adaptive policies arguably add an additional cost component to the overall cost of the policy, for the monitoring system and the required flexibility inside the system on which the policy act are additional sources for costs. In the context of the long term planning of airports, the ability to build or not build a runway, or the ability to quickly expand a terminal, require changes to the airport. For the runway, land-use reservations are needed. For the terminal, some form of flexible design using real options is required. The additional apparent costs of adaptive policies need to be offset against less uncertainty about the benefits. An in-depth analysis of the costs and benefits of adaptive policies as compared to traditional static policies is required to reveal the trade-off between on the one hand additional sources of costs necessary to create flexibility, while on the other hand having the ability to avoid unnecessary investments and thus reducing the overall costs of the policy.

How to address these four research challenges? With respect to the first research challenge, the first step is to make an inventory of methods and techniques that are used in current planning practice. Textbooks on policy analysis, systems analysis, (technology) forecasting, and (transport) planning are an ideal starting point for such an inventory. Next, the characteristics of the various techniques in the inventory need to be specified. The relevant characteristics can be deduced from the DAP framework: each step in this framework requires certain kinds of knowledge and each technique provides certain kinds of knowledge. The resulting mapping can reveal which techniques can employed where in the DAP process. The second research challenge focuses on the institutional implications of Dynamic Adaptive Policymaking. Addressing this research challenge could start from the literature on

institutional design (e.g. Ostrom 1990; Williamson 1997; Koppenjan and Groenewegen 2005). With respect to the third challenge, evidence can come from various sources −pilot projects, quasi-natural case studies, simulation gaming, computational experiments, and theory− and research on DAP should utilize these various sources (Kwakkel, Cunningham et al. 2009). To increase the empirical embedding of Dynamic Adaptive Policymaking, a focus on quasi-natural case studies is advised. The fourth research challenge focuses on assessing the costs and benefits of adaptive policies compared to traditional policies. A combination of Exploratory Modelling and Analysis and techniques currently employed to value Real Options executing is our suggested approach for addressing this challenge. These four research challenges are not of equal importance. We argue that research challenge 1 and 2 are the most important. Significant questions still exist with respect to the institutional implications of DAP and the available literature largely has ignored this issue. Analogues, the research on DAP needs to move beyond ad-hoc cases for illustrating adaptive policies and should start to address the questions related to how to actually develop adaptive policies.

Apart from these various research challenges, another avenue of work for researchers working on dynamic adaptation is the communication of their research findings to a wider, societal audience. Recent policy discussions, such as the health care debate in the United States, how to address the financial crisis, and the ongoing debate about how to address climate change, highlight both the problems society at large faces due to uncertainty, while also revealing the need for innovative ways of handling these. In the health care debate in the United States, the idea of a trigger was put forward. The financial crisis brought the problem of uncertainty and the vulnerability of society due to this clearly to the fore. While the ongoing struggle to address climate change shows how uncertainty can create deadlocks in decisionmaking. Dynamic adaptation points a way forward that does not rely on reducing uncertainty such as those surrounding climate change. It can potentially help to prevent another major financial crisis by explicitly considering ways in which policy can fail. It could have helped in crafting a more solid version of the health care trigger idea that might have made it into law. Regardless, these three examples reveal the potential benefits to society from dynamic adaptation research. Communicating to society on such issues and suggesting how dynamic adaptation can be of benefit is an important area of work for researchers working on dynamic adaptation.

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