

Chapter 2

Technology, Policy and Management: Co-evolving or Converging?



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2.1 Introduction

The TU Delft Faculty of Technology, Policy and Management (TPM), established in 1992 as the Faculty of Systems Engineering, Policy Analysis and Management, currently formulates its core business as *comprehensive engineering*: ‘*At the faculty of Technology, Policy and Management we combine insights from the engineering sciences with insights from the humanities and the social sciences. Our mission is to develop robust models and designs in order to solve the complex challenges of today’s networked, urbanized knowledge society. Our three closely collaborating departments address these societal challenges each with a different perspective: systems, governance and values. The smart combination of these three perspectives is at the core of Comprehensive Engineering*’. The three departments: Engineering Systems, Multi-Actor Systems and Values, Technology and Innovation represent core expertise in technology and engineering, the social sciences and the humanities, respectively.

In TPM’s evolution from systems engineering to comprehensive engineering, the Next Generation Infrastructures research programme (NGI) played a crucial role as a catalyst. Besides the aspect of substantial long-term research funding, enabling

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TPM to develop critical mass in terms of PhD students, NCI forced TPM to substantiate its interdisciplinary systems approach. NCI framed infrastructures as complex adaptive socio-technical systems which need to safeguard a range of public values. The field of infrastructure systems turned out to be a rich source of inspiring research questions and a trigger to leap from relatively small-scale research projects within disciplinary knowledge units to more challenging interdisciplinary projects and programmes. This brought TPM to reflect on the nature of interdisciplinary research and how to make socio-technical interdisciplinarity operational in terms of research methods and tools, and in education.

2.2 Socio-Technical Systems

Infrastructure systems defy traditional systems engineering approaches. Most infrastructure systems in the Western world evolved over decades, even centuries. Although each and every link and node of an infrastructure system is designed in the best traditions of engineering design, the system as a whole was never designed as an integrated system. System integration itself is an evolutionary process that advanced as a result of the progressive interconnection of local systems, regional and/or national systems. The physical establishment of pan-European railway, highway, electricity and telecommunications networks preceded the political agreement on the European economic union. Historical research revealed that the train journey from Paris to Moscow took less time around 1900 than today.

Infrastructure systems are always in flux, so that the notion of optimality has different meanings at different temporal and spatial scales. At the basic level of the physical network, new links are being added (or removed) at different spatial scales, whether at the level of international connections or at the level of new connections to new residences at the capillary level. Optimality from the perspective of an individual user may not coincide with optimality for another user or with optimality at the level of the national or international network. While the topology of the overall network is changing, the hardware is generally designed to last for decades. During the lifespan of the hardware, economic conditions and societal preferences are changing, new technologies come to the fore and end users impose new demands on the quality and reliability of service.

In interaction with the provision of infrastructure bound services, social norms and standards for personal and domestic cleanliness, comfort, mobility and social interaction have changed dramatically. Infrastructures apparently influence society and the economy at a far broader and deeper level than just providing the functionality they were designed to deliver. In turn, new patterns of behaviour in society and the economy enabled or induced by infrastructure provision, and changing societal preferences, shape the continued development of infrastructure in terms of technologies as well as institutions.

What all this boils down to is that the social domain cannot be considered a context variable; in infrastructure systems, the social domain is an indistinguishable

part of the system. The provision—or the absence—of infrastructure services affects the lives of all citizens. Infrastructure affects a range of competing public values, which need to be (re)balanced time and again. Moreover, in the neoliberal setting of most of today's infrastructure systems in the Western world, infrastructure development is the accumulated outcome of decisions made by a multitude of more or less autonomous actors, each with their own interests, values and means. In other words, infrastructures are not just exceptionally large technological systems: they are truly socio-technical systems. As many of society's grand challenges are directly and indirectly related to infrastructure provision, it is part of our academic responsibility to educate students in dealing with the complexity of these socio-technical systems.

2.3 Socio-Technical Systems in TPM's Education and Research

The Faculty of Technology, Policy and Management established in 1992 brought a radical innovation to the engineering education portfolio of TU Delft with the start of an interdisciplinary programme in Systems Engineering, Policy Analysis and Management (SEPAM), including a BSc and MSc programme. Until then, a selection of courses from the social sciences and the humanities had only been available as add-on electives to the traditional engineering education curricula. With SEPAM, and the TPM research programme emerging in parallel, TPM aimed to bridge the gap between engineering experts and the strategic decision makers in industry and public policy. It turned out to be the start of a rich and rewarding process of discovery. Initially, the best effort we were able to make was to present the students with two world views: one obeying the logic of science and engineering, and the other one a world of strategic agendas and multi-actor decision-making. How to confront and combine the social and engineering perspectives for better decision-making on real-world socio-technical systems was a case by case learning process.

Recognizing the need for a more systematic approach, we explicitly formulated the questions of understanding and governing infrastructures as complex adaptive socio-technical systems as core research challenges of NGI. It is then that we made the leap towards the development of hybrid analytical tools in which social and technical rationalities were integrated, with serious gaming (SG) and agent-based modelling (ABM) as prime examples. In SG, real-world players are the decision makers, whereas the system they govern is simulated to the extent of technical detail required to ensure the richness of behaviour that the players expect from the system, without which the credibility of the model and the players' engagement with the game would suffer. In ABM, social actors are simulated as software entities which are programmed, using state-of-the-art insights from behavioural sciences, to exhibit decision-making behaviour as observed in the real world, for example,

in terms of risk aversiveness, and under simulated real-world conditions, for example, in terms of incomplete information. Over the past decade TPM built an extended ABM platform for simulation of energy, industry and e-mobility, which now allows us to study interactions, e.g. between electricity and CO₂ markets, between interconnected national electricity markets and between electricity and gas markets, between globally dispersed production units across borders, while, for example, varying exogenous variables such as market design variables, technological learning curves and regulatory regimes. We are currently developing ABMs that model policy processes and policymaking as an endogenous process in the simulation.

Both types of hybrid models are especially in demand for support of strategic decision-making. They allow for experimentation with the regulatory context of socio-technical systems, showing patterns of system behaviour that may emerge as a function of certain governance variables. However, both types of models—in fact, any hybrid model, cannot be validated in the strict sense of validation. Even if historical system development can be reproduced, that in itself is not a true validation of the model.

The lack of rigorous validation seems to mistakenly disqualify hybrid models for productive use in times where policy is supposed to be evidence-based. On the contrary: ABM and SG allow for a far richer exploration of possible infrastructure system behaviour in the future than traditional technical or economic or behavioural models, which miss out on either the social or the technical complexity of the system, and which fail to address the interactions between the social and the physical dimensions. In the practice of strategic decision-making, however, it is not a matter of choice between traditional and hybrid models. The pertinent question is how to select the most relevant combination of analytical, optimization and simulation models and how to make sense of their outcomes. Hybrid models (not only ABM and SG) can contribute to that synthesis.

In the SEPAM education programme, the 3-year BSc programme focuses on thorough problem analysis. The 2-year MSc programme focuses on synthesis. Over the course of these 5 years, complexity is gradually increased in three parallel strands:

- (1) Technical specialization in one of four engineering systems domains:
 - Energy, Resources and Distributed Infrastructures,
 - Mobility, Transportation, Logistics and Supply Chains,
 - Water, Climate and Urbanizing Delta's, and
 - Cybersecurity, Innovations and (consequences of) Emerging Technologies in Cyberspace.
- (2) Governance (including policy analysis, public management, economics, finance, ethics, etc.).
- (3) Applications of methods and tools to actual socio-technical systems.

The BSc and MSc programmes were developed to seamlessly complement each other, ensuring a coherent interdisciplinary programme with a progressive build-up of social and technical complexity over the course of 5 years. The initial hesitation of some of the large industrial employers of engineering graduates to hire TPM graduates was soon overcome; TPM graduates easily find appropriate jobs in both the public and private sector, and their starting salaries are higher than for most of the traditional engineers. With the admission of undergraduates from traditional engineering programmes into the SEPAM MSc programme, starting in 2016, TPM is now confronted with the challenge of sensitizing engineering BSc's to issues of social complexity, and to ensure they acquire a sufficient knowledge base in social science to successfully complete the SEPAM MSc programme. On the basis of our experience with the Management of Technology and the Engineering and Policy Analysis MSc programmes, which admitted engineering undergraduates from the start, we know that it requires great mental agility for engineers to accept the social dimension as part of the system rather than as a context variable, and to embrace the social sciences in their own right, rather than employing superficial notions of the social sciences in an engineering framework.

2.4 Concluding Remarks

The intertwined histories of the TU Delft Faculty of Technology, Policy and Management and the national Next Generation Infrastructures programme have resulted in intensive cross-fertilization between engineering systems education and engineering systems research, between engineering and social science disciplines, between utility sectors, and between academia and practitioners. This unique co-evolutionary process has resulted in a number of undergraduate and graduate curricula and research programmes which distinguish themselves for their holistic approach to complex engineering systems as socio-technical systems. The hybrid models developed to substantiate TPM's interdisciplinary approach have had ample impact on industry and public policy, and TPM's graduates are firmly established now in strategic positions. These promising results do not guarantee future success. Especially in the institutionally fragmented multi-actor setting of infrastructure systems, the value orientations of stakeholders play an important role in their decision-making. Addressing the need for value-sensitive design is one of the challenges yet to be tackled in engineering systems education and research. We are tempted to speculate that rather than co-evolving, the engineering, governance and value dimensions of engineering systems are converging into a new science practice, the 'science' of comprehensive engineering, for which appropriate performance metrics still need to be defined.

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