FACING THE CHALLENGES OF COMPLEXITY: A PROCESS FOR MODELLING-BASED ROADMAPPING

Anna Leinonen

Aalto University School of Business, Department of Management Studies;

VTT Technical Research Centre of Finland Ltd., P.O. Box 1000, FI-02044 VTT, Finland, anna.leinonen@vtt.fi

Abstract

Today's policy-making takes place in complex world. Wide socio-technical changes require inclusion of multiple stakeholder groups and they deal with complex issues with diverse and sometimes conflicting values. In addition, the mechanisms of change and impacts of actions are not always clear or fully known. The combination of modelling in foresight is one approach that has been suggested for addressing these complexities and promoting better inclusion of foresight into decision-making.

This paper contributes to this discussion by proposing a foresight process, which incorporates modelling exercise into roadmapping process. First, the paper discussed the purposes of roadmapping and different understandings of models. Then it shows three case examples, which incorporated modelling into roadmapping to facilitate multi-stakeholder communication and co-design, and better understanding of the required change mechanisms. Deriving from the hands-on experiences, paper discusses the possibilities and benefits of modelling in roadmapping and builds a framework for understanding the different functions of modelling in roadmapping.

The framework consists of two dimensions. The first one is, the conception of roadmaps as a product, a visual strategy following certain representational conventions, and as a process integrating different perspectives. The other dimension represents the purposes that roadmapping can fulfil in policy analysis. The framework distinguishes four different functions for modelling in roadmapping: organizing the roadmap content, mediating interaction and communication in the roadmapping process, facilitating learning and analysing the systemic effects of actions. The paper discusses the types of models and the features of modelling exercises required for each of these functions.

Keywords: Roadmap process, modelling, framework

Introduction

Today's policy-making takes place in complex world. Wide socio-technical changes require inclusion of multiple stakeholder groups and they deal with complex issues with diverse and sometimes conflicting values. In addition, the mechanisms of change and impacts of actions are not always clear or fully known. The combination of modelling in foresight is one approach that has been suggested for addressing these complexities and promoting better inclusion of foresight into decision-making (European Union 2015). This paper contributes to this discussion by proposing a foresight process, which incorporates modelling exercise into roadmapping process.

Roadmapping was originally developed for technology management and long-term planning. It is a flexible technique, which can be used on various levels, in companies, as well as in industrial and political contexts (Phaal et al. 2004). In recent years, the use contexts of roadmaps have widened from product and technology roadmaps towards strategic and policy-oriented contexts (e.g. McDowall 2012; Tuominen & Ahlqvist 2010; Carayannis 2016).

In literature, roadmaps have been conceptualized as a product, a visual strategy following certain representational conventions, and as a process integrating different people and perspectives in making them (Kostoff & Schaller 2001, Phaal et al. 2004, Kerr & Phaal 2015). From the process perspective, roadmapping appears in literature mostly as a matter of process planning and workshop designs (Phaal et al. 2013). Despite the importance of the process perspective of roadmapping and its proposed communicational benefits, the aspects of communication and other strategic skills have been poorly addressed in roadmapping literature (Carvalho et al. 2013). The few exceptions cover an analysis of the relations between the level of interaction and the perceived roadmap credibility (Lee et al. 2012), as well as, cognitive and social factors affecting the interaction in roadmap workshops (Kerr et al. 2012a, 2012b).

This paper builds on practical experiences from the facilitation of roadmap processes, especially in policy-oriented context. Such processes require the integration of different stakeholders and actor groups into the roadmap creation, which creates challenges for interaction. To meet these challenges, I propose the integration of modelling into the roadmapping process. In the next section, I develop a typology, building on the purposes of roadmapping in policy analysis context and the conceptions of roadmaps as a product and process. The typology helps to identify different functions of modelling in roadmapping. After that, three case examples are presented. They are examples of different uses of modelling to facilitate multi-stakeholder communication and co-design, and better understanding of the required change mechanisms. Deriving from the hands-on experiences, paper discusses the possibilities and benefits of modelling in roadmapping and proposes a process model for modelling-based roadmapping.

Methodological approach

Roadmapping literature connects the benefits of roadmapping usually to the informative, co-ordination or communication functions of roadmaps. Roadmaps are seen as visual strategies that are *powerful communication mechanisms* (Phaal et al. 2004), which provide *information for planning and coordination* of science and technology development and for making better investment decisions (Kostoff & Schaller 2001). Roadmaps can set an *interlinked approach for long-range product and technology planning* and vision building, which can *shorten time-to-market* and thereby improve the competitive edge of a firm (Groenveld 2007). On the other hand, roadmap processes bring together people with different backgrounds, and provide therefore opportunities for *sharing information* and perspectives, *creating new ideas and addressing problems holistically* (Phaal et al. 2004). The roadmapping process may be a tool for *learning and cross-functional communication* in a firm, which introduces new process-oriented practices also to other functions, such as product specification process (Groenveld 2007).

The reported benefits of roadmaps highlight their dual character as a final product, a visual presentation following certain representational conventions, on one hand, and as a process, which integrates different people and perspectives to the creation of shared visions and plans, on the other. These aspects can be linked to the general flexibility of roadmapping method in the terms of the level of analysis (ranging from single technologies or companies to entire industries, disciplines, nations or international contexts), layouts of the roadmaps, or connections to other planning and monitoring tools (such as scenarios, portfolios or other strategy tools) (Moehrle et al. 2013). The flexibility of roadmapping method makes it a feasible tool for policy analysis, despite its origin as a technology management tool.

To understand the role modelling could play in roadmapping, we need to discuss first couple of meanings attached to the word model. Let us start from two everyday meaning for model. The first one is a *three-dimensional representation of an object*, such as architects' models of buildings. The second on is the understanding of *model as a normative or ideal*, for example a model parent or model organization. In his discussion on the role of models in social science, Blaikie (2010, p. 142) sets these meanings aside. He argues that they are not relevant for social research because such models may never exist in reality but are only ideals for which one strives. In the context of roadmaping, it is not necessary to abandon these meanings of model. As roadmapping always concerns future developments, it may benefit from understanding models as ideals to strive for or representations of something that does not yet exist.

In the context of social sciences, models can be understood as analogies between different fields (Blaike 2010, p. 152). In this case, theory or concepts from a better-developed field are used as a model for understanding another field. An example of such model would be seeing an organization as a living organism trying to adapt to its environment, and using it for guiding management theories. Understanding models in this manner would result in conceptual representations, in which the concepts and their relations are translated from one field to another. The accuracy of such models depends on the level of correspondence between the fields.

As shown above, some writers claim that roadmapping is inherently holistic approach. However, the practise of roadmap creation relies on the limited capacity of human participants to understand systemic elements of the topic at hand. System dynamic modelling, i.e. modelling the real world systems and their dynamic behaviour using conceptual and mathematical expressions, could be a useful tool to extend the human capacity of system thinking. Arnold & Wade (2015) define systems thinking as *a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects.*

System dynamic modelling requires special skills ranging from understanding the systemic nature of phenomena and their complexities, to mathematical analysis. When modelling is understood from this perspective, the modelling process involves analysing the system and its elements, setting the boundaries of the model and developing the model structure. The structure defines, how the model elements connect to each other, what kind of stocks and flows there are, and what kind of effects the different elements have on each other. The effects are analysed through feedback loops, which create the dynamics of the system. (Sterman 2002).

System thinking and system dynamic modelling could benefit roadmapping by providing means to analyse the effects of planned actions on the whole socio-technical system. As Sterman (2002) claims, there are no "side effects" of actions, but only effects that no one could anticipate beforehand. The other side of the matter is that system dynamic modelling is not an easy task. Critical aspects are the model boundaries and identifying the unconscious assumptions that may result in too narrow models. In addition, one needs numeric data for building and testing the model, which may cause additional costs and time pressures for the project.

To summarize the essence of models, it is necessary to differentiate the representational aspect of models from the explanatory use of them. Models are *representations* or *imitations* of something (a system, structure, or mechanism). Models can be *used for* explanatory or predictive purposes, presuming that the model represents the real system, structure or mechanism accurately enough. Another important aspect of models is that they are presented using certain representational conventions or "language". In this respect, we can differentiate models as diagrammatic (visual) and mathematical representations.

If one wants to include modelling in roadmapping process, there should be clear motivation or purpose for that. To analyse the possible purposes of modelling in roadmapping, we can derive from the overall purposes of roadmapping. Mayer et al. (2004) have developed a framework for understanding policy analysis as a discipline. Through a review of policy analysis studies, they have identified six purposes and styles of policy analysis. According to their review, policy analysis studies may support policy processes through research and analysis, design and recommendation, clarifying arguments and values, providing strategic advice, democratisation and mediation. Each purpose relates to different styles of implementation (Rational, Argumentative, Participatory, Interactive, Process-oriented and Client-oriented). In the framework (Figure 1), the styles locate between two activities, which suggests that each style balances on two important activities. For example, interactive style assumes that individuals, i.e. representatives of different social groups, may have differing views of the policy problems in question. The task of a policy analysis is to bring these people and views together to structure problems and devise solutions in structured working meetings. The balancing role between mediating and democratising purposes refers to the breath of inclusion of social groups in the process.

Referring to the benefits of roadmapping discussed above, we can locate roadmapping on the bottom right half of the policy analysis frame (Figure 1). Roadmapping is inherently process-oriented and interactive approach, which aims at providing strategic advice for a client or the "owner organisation" of the roadmapping process. The preparation of the roadmap, i.e. the process itself, is expected to mediate different perspectives for better-informed decisions and strategic advice. The next section presents three case projects, which illustrate how modelling may benefit these purposes of roadmapping.

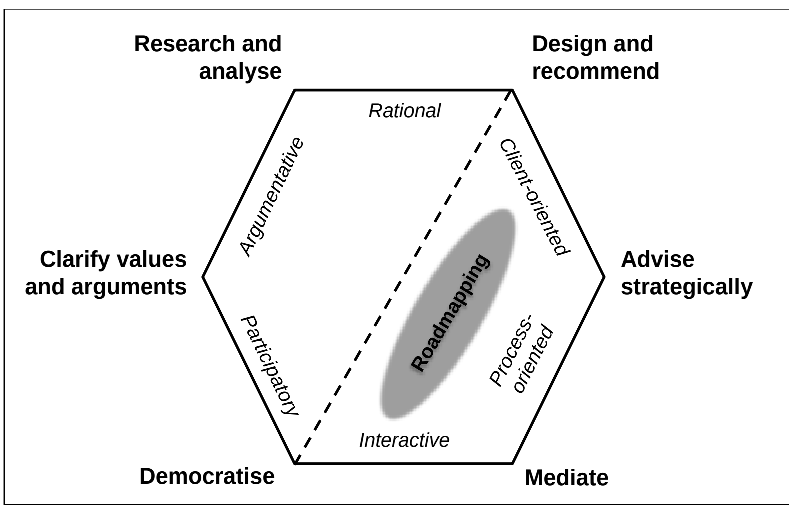

Figure 1. Roadmapping in policy analysis context using a framework by Mayer et al. (2004).

Results

In the following, I present three case projects, which each incorporated modelling in roadmapping. In each project, modelling had different function in the roadmapping process. This aspect is discussed at the end of this section.

Case 1: The first example is a project called SATORI (Stakeholders Acting Together on the Ethical Impact Assessment of Research and Innovation). It was funded under the European Union 7th Framework Programme and included seventeen partners from twelve countries. The aim of

SATORI project was to develop a common framework for the ethical impact assessment of science, engineering and innovation across, public, private and business sectors. An important principle was to develop the framework in dialogue with relevant stakeholders, including policy makers, research funding and administration organizations, public and private research organizations, industries, science journalists and Civil Society Organizations. (http://satoriproject.eu/)

SATORI project included a roadmap task, whose goal was to create a path towards fully developed Ethics Assessment framework and to support its implementation by different actors after the ending of the project. The work plan of the project did not include any budget for organizing interactive events, such as roadmap workshops. The idea had been to compose the roadmap using the extensive interview material that researchers had collected in a proceeding phase of the project. The utilization of this material appeared to be challenging due to communication issues in the working group. The representatives of the group came from two different organizations with completely different profiles and roles in the project. One organization represented expertise in roadmap methodology, while the other was strongly involved in the substance questions of Ethics Assessment. The representatives of latter organisation were involved in interviewing and analysing the interviews, but did not have any prior experience on roadmapping, whereas the roadmapping experts joined the project group at the start of roadmapping task and were not familiar with the interview material or the substance. This situation created a communication challenge in the group, which blocked the progress of roadmap creation for a while.

To open the block, we developed modelling approach, which was based on finding analogues to the development and implementation of the Ethics Assessment framework (Leinonen et al. 2017). This approach builds on the social scientific understanding of models as analogies (Blaikie 2010, p.151). i.e. using the concepts and theories of more developed fields to analyse other field. Examples of analogical models that we used in this case were Systemic Capacity Building model (Potter & Brough 2004) for understanding institutional requirements of the change and Theory of Planned Behaviour (Ajzen 1991) for individual behavioural changes. The resulting model was a diagrammatic representation, which indicated the various systemic levels and general action classes distributed on a time scale according to their difficulty. The model helped us to structure the roadmap and overcome the communication gap in the working group. We were able to connect individual findings (proposed actions) from the interviews to the general action classes and their time scales of the model. This way we were able to outline a draft version of the roadmap, which was then discussed in an extended project group and with some stakeholders. These discussions reviled that more effort would have needed to the development of the visual structure of the roadmap, which was perceived rather complicated.

Case 2: It seems that the full potential of the modelling approach could be reached if stakeholder insight were collected after model construction. The second case example, a project with an educational focus, illustrates this approach. The content of the project was a training pilot “Doctor in Residence” within RTOs and industries in the Raw Materials sector. The goal of the educational pilot was to develop skills and knowledge that are needed for boosting innovations and generating new business ideas. To achieve this, the goal was to develop “T-shaped innovation champions”, who have deep substance (technological) knowledge and extended knowledge on business and sustainability issues. The project received funding from the European Institute of Innovation and Technology (EIT) under the Horizon 2020 framework program and included five partners (RTOs, Unversities and Industries) from two countries. (https://www.vtt.fi/sites/TDore/)

In addition to the educational pilot, the project contained a roadmapping task. The goal of roadmapping was to create concrete guidelines and actions for the development of T-shaped innovation champions for the Raw Materials sector by scaling up the findings of the pilot project. Once again, this was a challenge for roadmapping, which raised many questions. How to generalize findings from a single, small pilot project to institutional level? How to create concrete and common guidelines in educational field, which has many national differences? How to communicate and collect stakeholder views in a short time span of the project for a roadmap with relatively abstract and undefined goal? To respond to these challenges, we started the roadmapping task by creating three different educational models. The models were drawings identifying educational paths and actors whose contribution is needed for the realization of each model. The distinguishing factor of each of the three models was the main organizer of the education and the profiles of intended participants.

Primarily, the models served communicational purposes in the roadmapping process. First, the drafting of the models supported communication among the project group by concretizing discussion. For example, the modelling exercise reviled some differences in the implicit goals attached to the project. Second, we used the models in interviews and workshops for communicating the goals of roadmapping and collecting stakeholder input. When we used the models as a starting point in stakeholder discussions, it was possible to identify national differences in educational systems and possible consequences that these differences could create for implementation.

Case 3: In the previous cases, modelling was rather simple exercise, while the third roadmpping example contains more demanding modelling. This example is from a project that aimed at developing methods and tools to support decision-making in complex transition context, such as emission-free transport systems (Auvinen et al. 2015). The developed method combines approaches from the fields of foresight, impact assessment and simulation modelling into stepwise iterative process. The five steps are the following: (1) Identification of the decision-making situation, (2) Analysis of the socio-technical system, (3) System transition roadmap, including vision paths and policies, (4) System dynamics modelling and simulations, and (5) Interpretation of the results. The process is not linear, but feedback loops from the final step may require iteration of the previous phases.

The process was developed using a demonstration case with the target of emission-free transport in certain city area. The first step includes the identification of strategic objectives (e.g. from policy documents) and the formulation of a vision statement. This work provides for information to the next steps. The second step identifies the components and elements of the relevant socio-technical system. The relations between the different parts of the system are then analysed by drawing causal loop diagrams, which identify the variables, the feedback effects between them, as well as, stocks and flows and time delays of the system (Sterman 2002). The composition of the diagrams increases understanding of the current socio-technical configuration. The third step is a roadmapping exercise, which outlines the transition paths to the vision. After that, it is possible to build a system dynamic model (using the causal-loop diagram developed in step 2) and use it for simulations to test the feasibility of the vision paths (identified in the step 3).

The benefits of the method, as discussed in Auvinen et al. (2015), are that it enables a truly future-oriented approach to the analysis of socio-technical changes, and can this way channel the change. By combining the simulation modelling into roadmapping process, it is possible to examine the interactions of various change processes and analyse the impact of various policy mixes, e.g. reveal the possible undesired side effects of different policies. An additional benefit of the modelling approach is that it enables to consider the user perspective and behavioural aspects in the analysis of socio-technical changes. Building the simulation model and running the simulations create an opportunity for learning and understanding the socio-technical system and its elements and linkages. This may be a useful outcome of the process, even if the system could not be modelled in full accuracy. The latter aspect is a factor that can be seen as a limitation of the approach. The results of the simulation phase need to be interpreted carefully bearing in mind that they show how specified assumptions can generate a certain qualitative dynamic behaviour of the system. Due to the inherent uncertainties of complex socio-technical systems, results cannot be treated as accurate quantitative predictions of the system behaviour.

To illustrate the different functions of modelling in the above roadmapping examples, we can use the aspects discussed in the methodology section. First, we identified the mediation and advising functions as the main purposes of roadmapping and indicated that modelling should support these purposes. The second aspect was the dual character of roadmaps as a product and process. These dimensions create a framework for understanding the functions of modelling in roadmap processes (see Figure 2). The framework distinguishes four different functions for modelling in roadmapping: *organizing the roadmap content*, *mediating interaction and communication* in the roadmapping process, *facilitating learning* and *analysing the systemic effects of actions*. The first two cases were examples of projects where modelling predominantly served the mediation purpose (left side of the framework), and the third case was an example of modelling for advising purpose (on right).

	Mediate	Advise
Roadmap as a product	Models for organizing the roadmap content	Models for analysing the systemic effects of actions
Roadmap process	Models for interaction and communication	Models for learning

Figure 2. The functions of modelling in roadmapping.

Discussion and implications

This paper discussed how modelling can contribute to roadmapping. The views presented rise from practical experiences from the facilitation of roadmap processes. I showed that modelling could serve different functions in roadmapping, which are derived from the two main purposes of roadmapping: mediating different perspectives and formulating strategic advice. For both main purposes, it is possible to identify two additional dimensions of roadmapping: roadmaps as a product and the process of creating them. Table 1 shows these different functions and identifies the various types of models connected to each of them.

Models used for mediation purposes can be simple diagrammatic representations, which are created in the course of roadmapping work. In this respect, one can separate two different types. “Architecture models” borrow from the idea of using 3D models in architecture to create impressions of future buildings or residential areas. Similarly, in roadmapping this kind of models could communicate the future structures or development goals. When models are used for organizing the roadmap content, they can be build utilizing analogues thinking. This means that the change mechanisms under consideration are analysed by using concepts and theories from more advanced fields. In this case, modelling involves literature review and consideration of possible analogies between different fields. These models can be particular useful for organizing the roadmapping content, but also for mediating the interaction process if they are used for inspiration in creative phases of roadmapping process.

If one intends to use models for advising purposes, modelling becomes more demanding task. It requires extensive analysis of the socio-technical system in question and the policy and decision making conditions. The third case presented in the previous section showed the usefulness of system dynamic modelling and simulation in the analysis of complex socio-technical changes. The benefits of system dynamic modelling and simulation comes, especially, from the learning factor. The modelling exercise provides a tool for learning about the interactions and systemic impacts of policy mixes. This kind of modelling requires special modelling skills and is more time-consuming compared to the simple models of the previous group.

Table 1. Modelling functions and types in roadmapping.

Modelling functions in roadmapping		***Model types***	***Model representation***
Supporting Mediation purposes	Organizing the roadmap content	Analogy models	Diagrammatic representations
	Interaction and communication	“Architecture models”	
Supporting Advising purposes	Analysing the systemic effects of actions / policies	Simulation models (System-dynamic modelling)	Predominantly mathematic representations
	Learning	Conceptual models, Causal-loop diagrams	Diagrammatic representations for supporting mathematical modelling

Figure 3 shows a proposal for modelling-based roadmapping process. At the beginning, it is necessary to analyse carefully the roadmapping task, its objectives and how modelling can contribute to the goal. At this point, one need to decide whether the primary purpose of modelling is the mediating or advising function. This choice defines how demanding the modelling task will be and how much resources are required for it. As mentioned before, modelling for mediating purposes does not require specific skills, but rather is a certain kind of mind-set that is adopted in the process. For this purpose, useful models can be diagrammatic representations, which concretize the issues at hand. Such models are useful for mediating creative thinking and communication, identifying gaps and actions that are required for bringing forth a change and achieving the desired goal. Modelling for advising purposes is more complicated task (the lower part of Figure 3). It requires more time, resources and special skills. In this case, roadmapping becomes an iterative process where vision paths are analysed using simulation models, and simulation results are fed back to roadmapping to adjust and focus the roadmap content.

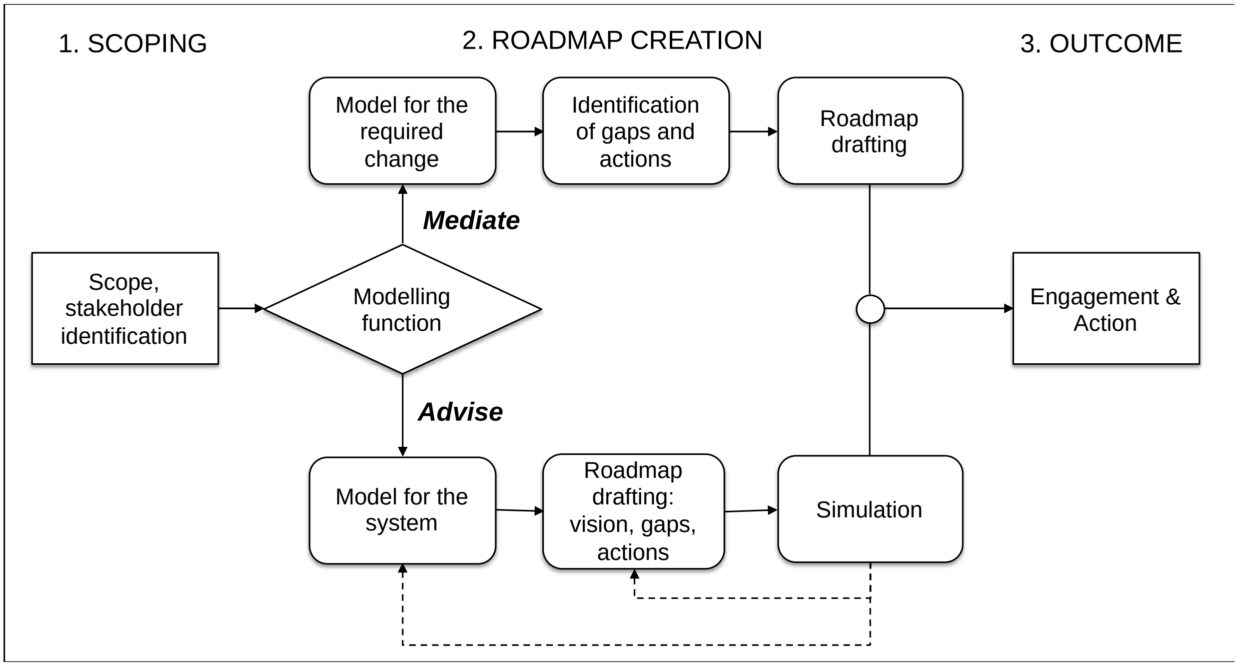

Figure 3. Process model for modelling-based roadmapping.

As was mentioned in the introduction, aspects concerning interaction and communication are under-covered in roadmapping literature. Modelling approach may bring clear benefits to roadmapping processes from this perspective. As modelling exercises mediate communication among roadmap working groups and in stakeholder workshops, they may shorten the processes of roadmap creation. The analysis of systemic socio-technical changes is more complicated and therefore involves more time-based risks. In order to be able to build the system dynamic models, the socio-technical system in question and the interdependencies in it need to be known in certain degree. This involves that there should be historic data of such systems available for modelling. In the interpretation of the simulation results, good substance knowledge is essential. Simulation results increase understanding of the system and its interconnections and can therefore contribute to better policy measures. On the other hand, numerous iteration rounds may be time-consuming, and cause delays in the process. Complex socio-technical systems are challenging objects for modelling but even if the simulation results were not completely accurate, the process itself can provide significant benefits by mediating learning. The full potential of modelling-based roadmapping is yet to be found through more practical experience in roadmap projects.

Conclusions

This paper discussed the potential of integrating modelling in roadmapping processes. Deriving from practical experiences in three different roadmap projects, I presented a typology for identifying the different functions of modelling in roadmapping process. Models may provide means for structuring the roadmap and channelling the interactive parts of information gathering, such as workshopping activities with stakeholders, towards relevant questions. The modelling exercise provides a possibility for communication and iterative learning, when the change dynamics or impacts are unknown. Simulation models can be used for analysing socio-technical change conditions and the impacts of different policy mixes on different sub-systems. For each purpose, one needs different types of models ranging from simple diagrammatic drawings to complex simulation models.

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