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A functions approach to improve sectoral technology roadmaps

Carolina R. Haddad, Mauricio Uriona Maldonado *

Federal University of Santa Catarina, Department of Industrial and Systems Engineering, Campus Universitário, Trindade, Florianópolis, SC. 88040-270, Brazil

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ABSTRACT

The roadmap approach has been used to develop future-oriented analysis (FTA) linking technology/innovation, policy, business and social drivers. There has been a growing interest in introducing a systems perspective within the roadmap approach, especially at sectoral level. This paper proposes the use of the 'functions of innovation systems' as drivers/layers within sectoral roadmaps, with the purpose of directing decision-making and policy-making efforts towards the functions. We provide the case study of a sectoral roadmap exercise aiming at establishing a non-existing automotive sector in Santa Catarina State, Brazil (a sector which does not exist at present time in the region) by means of integrating the 'functions approach' with the roadmapping process. We find the 'functions approach' to be a useful approach to support the development of future-oriented analysis by making explicit the current and desired future states of each system's function.

1. Introduction

Future-oriented Technology Analysis is a projection, to the future, of current knowledge and has as main role to assist societies, decision makers and businesses to tackle difficult decisions when it comes to technology and its impact on economic development (Daim and Oliver, 2008; Cagnin et al., 2013). Due to the potential of FTAs in enabling a better understanding of complex problems and in defining more effective policy responses, interest in studying its theoretical and practical implications has grown, see for example the Special Issue in *Technological Forecasting and Social Change*, edited by C. H. Cagnin, A. Havas and O. Saritas in 2013.

Among the many FTA tools, the roadmapping approach has become widely popular during the last decade and has been adopted by companies, governments and other organizations, due to its capability to link technology/innovations, policy and business/social drivers (Garcia and Bray, 1997; Lee and Park, 2005; Daim and Oliver, 2008; Saritas and Aylen, 2010; Carvalho et al., 2013; Moehrle et al., 2013). As it can be verified in the previous literature, there are two main traditions of roadmapping: corporate roadmaps, which relate to the development of temporal and graphical means to explore and communicate the relationship between markets, technologies and products (Phaal et al., 2004a, 2004b; Lee and Park, 2005); and roadmaps at sectoral and national levels, which relate to the development of visual narratives describing multi-layered strategy maps of both, the macro-level currents and the micro-level developments (Blackwell et al., 2008; Phaal and Muller, 2009), in order to identify trends (Lee and Park, 2005) and forward-looking policy design (Ahlqvist et al., 2012).

In recent years, there has been a growing interest in introducing a systems perspective within the roadmap approach, especially at sectoral level (see for example, Ahlqvist et al. (2012) and Saritas and Oner (2004)). Following this line of practice, the paper introduces the concept of 'innovation systems' and more specifically, the 'functions of innovation systems' into the roadmapping process (Alkemade et al., 2006; Hekkert et al., 2007; Bergek et al., 2008). In this sense, each system function serves as one dimension of analysis for the roadmap (i.e. the drivers). In order to demonstrate the usefulness of this proposal, we provide the case study of a sectoral roadmap exercise aiming at establishing a novel automotive sector in Southern Brazil (a sector which does not exist at present time in the region).

Our main argument is that the system functions serve to map the current state of the sector and the desired future state of the sector, providing policy makers with a richer set of guidelines to draw on, in order to build the roadmap from the current to the future state. Similar work can be found in Andersen and Andersen (2014), Andersen et al. (2014) and Alkemade et al. (2006).

This paper is structured as follows: in Section 2 we briefly review the previous literature on sectoral technology roadmaps. In Section 3 we outline the theoretical framework integrating the 'functions approach' with the roadmapping process. In Section 4 we provide a case study in Brazil. The purpose of the case study is to demonstrate how the 'functions approach' can be utilized in the roadmapping process of a yet-to-exist sector. In Section 5 we provide the synthesis of the main contributions as well as the discussion and conclusions. We conclude with the acknowledgments and references sections.

* Corresponding author.
E-mail address: m.uriona@ufsc.br (M. Uriona Maldonado).

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2. Previous literature on sectoral technology roadmaps

Technology roadmaps (TRM) were originally used in the corporate domain. Probert and Radnor (2003) reported Motorola and Corning as the first companies to use the approach in the late 1970s and early 1980s. Geum and Park (2012) reported many studies developing the field of TRM, by studying its characteristics (Phaal et al., 2004a, 2004b), its types (Kappel, 2001; Phaal et al., 2003; Lee and Park, 2005) and formats (Phaal et al., 2004a, 2004b; Lee and Park, 2005). These exercises were mainly focused at the corporate level, with the purpose of developing strategic, process, product, capacity, integration, and long-term plans as well as between operational units of the company (Probert and Radnor, 2003). Kostoff and Schaller (2001) categorize these roadmaps into four categories: (i) product/portfolio management (ii) Science & Technology; (ii) industry technology; and (iv) corporate or product-technology.

In addition to the corporate roadmaps, there are a variety of other roadmapping exercises found in the literature. For example, Phaal et al. (2004a, 2004b) proposed a variation of the fast-start process, extending beyond the roadmap for product technology planning, called T-Plan to the S-Plan, which involves broader applications. The S-Plan was developed with the aim of Identifying and exploring strategic, innovation and business opportunities (Phaal et al., 2007).

Walsh (2004) based on the traditional TRM approach, proposes a model for disruptive technologies. Geum and Park (2012) explore the state of the art in relation to the development of roadmaps for the public sector, arguing that these are particularly distinct of corporate roadmaps. In this sense, the authors come to four main types of technology roadmaps for the public sector: (i) action-based; (ii) pathway-based; (iii) technology-based; and (iv) vision-based. Yasunaga et al. (2009) illustrate goals, structures and methodologies for roadmapping application for national technology policy, arguing that this approach can assist the preparation of government R&D policies and generate discussions about relevant policy indicators. Rinne (2004) explores how technology roadmaps support virtual innovation and argues roadmaps can be important drivers of innovation, as they allow the convergence of foresight and innovation, represent the co-evolution of technologies and markets, and contribute to technology organization over time. Simonse et al. (2015) built a model for innovation roadmapping and point out the effects on innovation performance of competitive timing and industry sinergy.

On the other hand, another stream of literature sought to combine a 'systems perspective' with the roadmap approach. Morioka et al. (2006) focus on the innovation system of the Research Institute for Sustainability Science (RISS) and propose a technology transition management based on technology push, demand pull and institutional design to develop this system. Komninos et al. (2011) developed an innovation roadmap that combines regimes and new solution niches (technological, industrial, social, and policy change) to support the development of innovative policies and strategies for Smart Cities and the Future of the Internet. Almeida et al. (2015) present the methodological tool used for the creation of the future vision and agenda for a National Innovation Initiative (NII) in three emerging technologies in Brazil. This instrument integrates methods of technology foresight, technology roadmapping and Delphi for the formulation of public policies, identifying emerging technology areas and prioritizing RD&I efforts.

Ahlqvist et al. (2012) propose the Innovation Policy Roadmapping (IPRM), a methodological framework that connects the results of R&D to the innovation systems context for policy design. Therefore, the IPRM integrates technology and social environment analysis to make future-oriented analysis, listing the results of the survey to policy design in five ways: (i) building a common vision; (ii) facilitating systemic change by identifying social needs that require new solutions; (iii) anticipating the emergence of a new market; (iv) understanding the interdependence of the different layers of the roadmap; (v) identifying specific innovation targets.

The IPRM is based on two traditional exercises: technology roadmapping, with respect to the legal instrument of technology identification and its alignment to product planning and action plans, and strategic roadmapping, which involves a dynamic and interactive process.

In structural terms, the authors divide the IPRM on two levels. The first level corresponds to the systemic transformation roadmap, which aims to understand the technological development and its socio-economic frameworks to support policy-making. Its architecture consists of four levels: (i) drivers, (ii) policies, (iii) sectoral development; and (iv) key enablers. The second level corresponds to the technology roadmap, which is a sub level of the key enablers step and is formed by the long-term vision defined in the previous level. The structure of the technology roadmap can have up to four sub-levels, depending on the analyzed topic: (i) technology-based solutions; (ii) enabling technologies, convergence; (iii) needs and markets (segments, geography); and (iv) capabilities, resources, actors (CRA).

To illustrate how the political perspective can be built in the dynamic context, the authors analyzed two case studies: the roadmap of green and intelligent buildings in Australia and the roadmap of environmentally sustainable ICT in Finland. This approach has two main contributions to the use of roadmaps for policy design: (i) the IPRM emphasizes the systemic benefits of foresight, integrating many stakeholders to build a shared long-term vision; (ii) the roadmap identifies gaps and the interdependence of the components of the system (Ahlqvist et al., 2012).

At the sectoral level, specifically, roadmaps have been developed for more than two decades. Among the sectors that applied technology roadmap, we can mention mobile communications, chemicals, automotive, energy, software, nanotechnology, mining, academic services, construction, medicine, hydrogen, telecommunications (Carvalho et al., 2013) and semiconductors.

In the latter sector - semiconductors - as well as studies in different countries (Kostoff and Schaller, 2001; Garcia and Bray, 1997; Allan et al., 2002; Edenfeld et al., 2004; Carballo et al., 2014) there is also a study called the International Technology Roadmap for Semiconductors (ITRS), which is updated every two years, and is one of the most successful and disseminated example of sectoral roadmaps (Kajikawa et al., 2008).

There are other numerous examples of sectorial roadmaps, as the roadmap process in the energy services sector at Bonneville Power Administration (BPA) in the United States (Daim and Oliver, 2008). This was drawn from three main stages: planning, training of those involved in the roadmapping process, and implementation and development of the roadmap. To undertake the construction of the roadmap, they analyzed drivers, desired products features, technology and R&D. Another example is the UK Foresight Vehicle Technology Roadmap (Phaal, 2002), which examined a number of trends and drivers, measure performance and targets, and technology and research to indicate strategies for the road vehicles sector considering a 20 years vision.

We can also mention the South Australian Cellulosic Value Chain Technology Roadmap (Ahlqvist et al., 2013), who used the concepts of path dependence, path creation, and the theories emphasizing evolutionary aspects of economic agglomerations and emergence of clusters to develop a strategic roadmap. Thus, the authors created a model, considering the industrial, cultural, environmental, financial, regulatory and R&D aspects, to renew the forest industry. In addition, the ICT for Environmental Sustainability Roadmap (Ahola et al., 2010), built a meta-roamap considering drivers, bottlenecks, services, products and markers, and enabling technologies. Then, in a second level, they developed three sub-roadmaps, using the same variables: empowering people, natural resources extending and optimizing systems.

Besides these, there are numerous other cases of sectoral roadmaps. The International Energy Agency (IEA, 2016), for example, presents a series of global roadmaps, focused mainly on low-carbon technologies, including bioenergy, biofuels, and so on. The Agency makes an analysis in terms of "technology development, legal/regulatory needs,