Integration of Technological Changes into Long-term Planning: Agent-Based Modeling Approach

Miguel Angel Toro-Jarrin, Andrew J. Collins, Ph.D.
Old Dominion University
Norfolk,VA
mtoro001@odu.edu, ajcollin@odu.edu

ABSTRACT

Planners use tools to generate and handle information to make decisions that affect the future of their organizations. These tools include forecasting, scenario analysis, technological road mapping, among others. They help planners in systematically explore the future, however sudden changes that new technologies have caused before in organizations evidence that existent tools fail considering emergent technological advances in their planning process. To enhance understanding about the effect of technological advances cause in the planning process in an organization, this paper proposes incorporating the feedback from technological change into a strategic planning. We will explore using agent-based modeling simulation (ABMS) to capture the affectation of a high-level strategic discourse in the individual customer/client/user. We will stablish the strategic planning process using a Technological Roadmapping (TRM), a device that provides chronologically the relation of social trends – technologies. This hybrid model will provide a means to include emergence into a roadmapping process and it will increase the understanding of the inclusion of modeling and simulation into the decision-making process. The paper outlines the proposed hybrid approach including a possible method for future implementation.

Keywords
Agent-Based Modeling Simulation, Hybrid Modeling, Technological Roadmapping.

ABOUT THE AUTHORS

Miguel Toro Jarrin is a Fulbright awarded - Ph.D. student at Old Dominion University in the department of Engineering Management and Systems Engineering. His research interests are: 1) the dynamics of sociotechnical transitions, 2) the mechanisms for operationalize frameworks that represent such transitions, 3) Its application in identifying technological transitions to come to help organizational and institutional readiness.

Andrew J. Collins, Ph.D., is an assistant professor at Old Dominion University in the department of Engineering Management and Systems Engineering. He has a Ph.D. in Operations Research from the University of Southampton, and his undergraduate degree in Mathematics was from the University of Oxford. He has published over 70 peer-review articles. His projects have been funded to the amount of approximately $5 million. Dr. Collins has developed several research simulations including an award-winning investigation into the foreclosure contagion that incorporated social networks. His website and full resume are at www.drandrewjcollins.com.

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INTRODUCTION

Ringland defines strategic foresight as, *"the ability to create and maintain a high-quality, coherent and functional forward view, and to use the insights arising in useful organizational ways. For example, to detect adverse conditions, guide policy, shape strategy, and to explore new markets, products and services. It represents a fusion of futures methods with those of strategic management."* (Ringland, 2010) However, it is arguable that such process is completely achivable when changes happned fast and are some cases sudden. For Chermack, *"it seems clear that executives are increasingly struggling to understand and anticipate changes in their environments."* (Chermack, 2007) he adds, *"it may be a mistake to work toward the ability to predict the future—but the ability to predict that processes aimed at coping with the future are effective is extremely important."* (Chermack, 2007) As an attempt to combine research about technological trends and its social impact, authors and practitioners have been used several tools such as Technological Roadmapping (TRM), scenarios, future studies, and others (Chermack, 2007; Pillkahn, 2008; Probert et al., 2013; Ringland, 2010; Routley, Phaal, & Probert, 2013). It is arguable tough, that these tools can represent the feedback from the customer/user/client standpoint. This work will explore specifically such feedback using a TRM process as a planning tool and agent-based modeling simulation (ABMS) to reproduce the effect of strategic decisions at the individual level into the long-term planning.

An example of how a technological changes affectation is an organization that uses modeling and simulation (M&S) as a primary product and tool of its activities. And even more, those changes affect the entire discipline in this example, M&S. For example, in the 1950s, Keith Tocher released the General Simulation Programming (GSP), which was the first general purpose simulation software (Tocher & Owen, 1960). GSP allowed creating simulations in a much more efficient and affordable manner. The 1980s saw the discovery of time-saving algorithms, like Common Random Numbers (CRN) (Leemis & Park, 2006), which allowed more efficient stochastic simulation configuration, and Latin Hypercube sampling (McKay, Beckman, & Conover, 1979), which helped more efficiently explore the sample space. In the 1990s, simulation advances parallel those of the video gaming industry especially the rise of 3-D graphics (further discussion in (Collins, Knowles Ball, & Romberger, 2015; A. M. Law, 1990)). This resulted in more accessible advanced visualizations, especially for training purposes providing benefits to a broader community. The 2000s saw the introduction of Agent-based Modeling and Simulation (ABMS) due to the desire to use simulations for understanding complex phenomena as opposed to well-understood systems, e.g., a manufacturing job shop. The introduction of ABMS has caused controversy within the simulation community (Hoad & Watts, 2012; A. Law, 2015) because of its focus on understanding the phenomena as opposed to providing definite solutions (Epstein, 2008); or as Huntington (Huntington, Weyant, & Sweeney, 1982) put it *"modeling for insight, not numbers."* The 2000s also saw many other changes due to the rise of the personal computer market which made simulation software available to everyone not just those with high-performance machines. In recent years, due to the affordability of the technology, there has been an increase in the use of Virtual Reality (VR) and Augmented Reality (AR) within simulations. These changes have advanced the field of M&S but they came from different disciplines. Those organizations that use M&S as their primary activity and product, needs to have a sense of those changes in order to plan proactively (Godet, 2010).

Giving the impact that these changes produce in an organization that has not plan for these changes we need better ways to visualize and represent them in a planning process. It is a valuable depiction one that reflects the current and the future state of things for an organization - institution and how to make a better position possible. We need to identify mechanisms to understand sociotechnical systems and their mechanisms. Furthermore, we need to operationalize those mechanisms. This work presents a strategic planning process performed with a technological roadmapping process. The strategic planning give strong references for a better modeling stage of an agent-based modeling process. Finally, we bring the feedback from agency to the strategic planning again.

The next sections contain introductions of a technology roadmapping process (TRM) and agent-based modeling simulation (ABMS) as the tools of choice. We present past experiences of integration between ABM and other tools. Finally, we present an introduction of our approach TRM – ABMS for representing emergence in a strategic plan of resources.

TECHNOLOGICAL ROADMAPPING (TRM)

Public and private organizations scan the environment to plan for the best outcome possible or to prepare for adverse effects of a negative event. With this aim, there are several tools, methods, and methodologies, among them, technological roadmapping (TRM). TRM is a systematic approach that presents the result of multiple analysis, graphically and chronologically distributed (Phaal, Farrukh, & Probert). It is a depiction of the environment around the organization in three levels, social, product, and technologies. Figure 1 presents the elements of analysis that TRM includes according to Phaal et al. (Phaal et al., 2011)

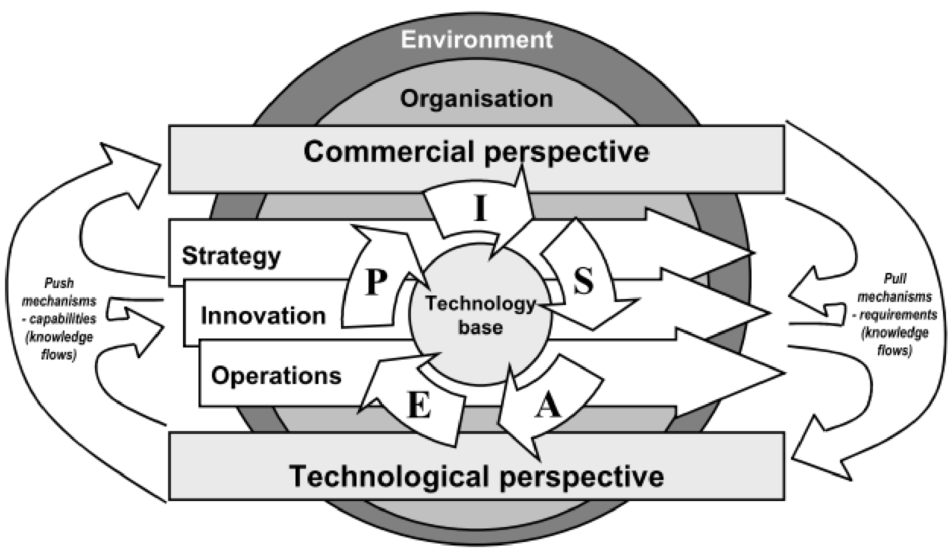

Figure 1. ***"Technology management framework showing the technology management processes (Identification, Selection, Acquisition, Exploitation, and Protection). It shows the business process (strategy, innovation and operations) and it highlights the dialogue that is needed between the commercial and the technological business to support effective technological management."*** **(Phaal, Farrukh, & Probert, 2001)**

One strength that the TRM is the amount of information that carries to inform decision makers. It contains the market elements that pull value out of the organization and the technological elements that generate that value. It contains three levels of abstraction: 1) high level reflecting the environment (social, political, economic elements); 2) intermediate level of products and services that generate value, and 3) operative level, which reflects the technologies, skills, partnerships, and other elements that allow the design, construction, and deliverance of value creators. Finally, a TRM presents the levels and their elements presented chronologically from the present to the long-term future.

Figure 2 sumarizes the elements of the TRM. The levels in the framework are not independent; they are interrelated and are ignitors of one another. The trends existing at the strategic level pull product and services that better solve societal problems. These product and services need specific technologies, capabilities, skills and so on. For developing those, an organization invest in Research & Development (R&D), but it only partially plan this effort. Non planned investments from many other parties will promote technological alternatives that if nurtured will flourish and can become dominant technologies (Schot & Geels, 2007). Finally, the discussion and bring collaborators from different departments, *"stimulates organizational learning through the encouragement of openness and ways of doing things better. It also supports people at all levels in achieving milestones and becoming committed to their role in the overall process."* (Groenveld, 2007)

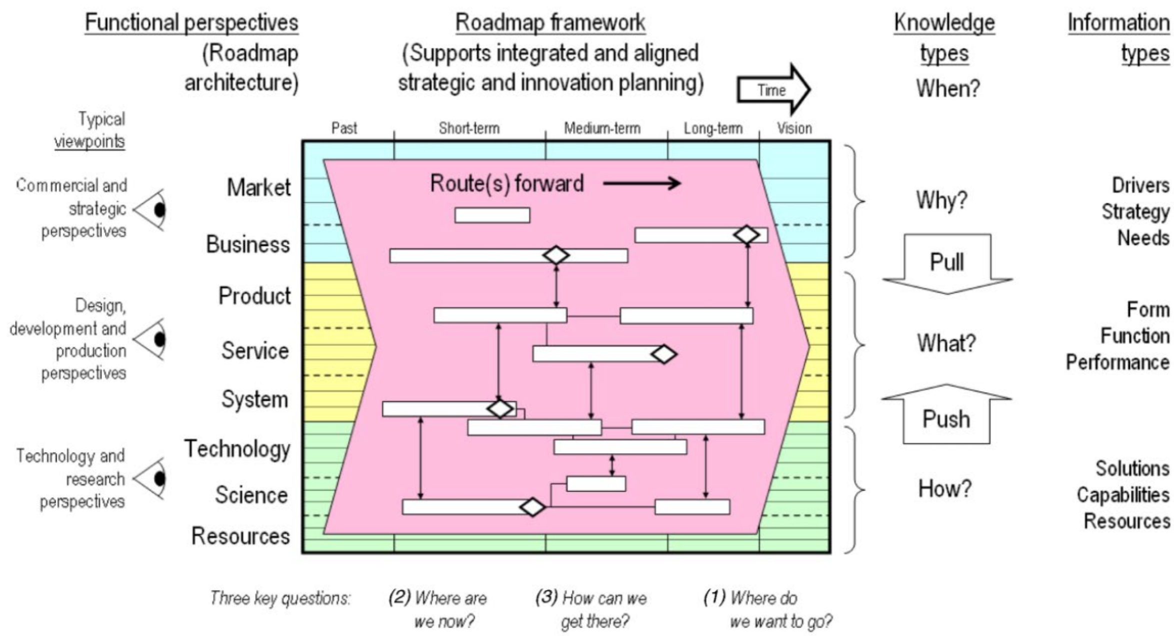

Figure 2. Technological Roadmap (Kerr, Phaal, & Probert, 2012)

In order to have a first cut of a TRM the literature suggests one-day workshop for each of the major levels (market, product, and technology) plus one more preparatory stage (Phaal, Farrukh, Mitchell, & Probert, 2003; Toro-Jarrín, Ponce-Jaramillo, & Güemes-Castorena, 2016). In the preparatory stage a champion (the person that lead the strategic effort), defines the goal of the roadmap, the time-horizon of the roadmap, and the members of the team. In the introductory stage, the team discusses the goal proposal and agree on it. The team establishes *"(a) where does the firm want to go? (b) Where are they now? Also, (c) how can they get there?"* (Toro-Jarrín et al., 2016) The first workshop analyses the environment where the firm operates. The panel answer guided questions addressed to define; political strategy, macroeconomic forces, key trends, market forces, industry forces, customer relations, business strategy, and performance dimension. The second workshop contains the product analysis where according to Toro, are discuss four areas; new entrance, substitutes, product strategy, and product identification. The third workshop is the technological analysis where the team discusses industry forces, technology forces, operational and technological strategy, key trends and technological features.

TRM has been broadly used in industry and government. For instance, in 2015 the Association Connecting Electronic Industry developed a technology roadmapping for electronic interconnections (Industry, 2018). The report, *"provides vision and direction for product and process development and the services required to satisfy current and future needs of companies that design, build, buy or specify electronic equipment and materials."* (Industry, 2018) In government the applications are broad. For example, Van Duin et al. use a dynamic technological roadmap to develop, *"a scenario-based, multi-stakeholder, adaptive pathway approach, with an application for city logistics policies in 2025."* (Van Duin, Bauwens, Enserink, Tavasszy, & Wong, 2016)

There have been multiple integration process between TRM and other tools and methodologies for strategic planning (Amer, 2011; Bezold, 2010; Lee, Song, & Park, 2015; Rialland & Wold, 2009; Toro-Jarrín et al., 2016). In this work, we explore the integration of ABMS and TRM with the purpose of substantiating agent-based modeling with contextual elements and inform a roadmapping process about the emergence of the agency. The ultimate purpose is making a more robust tool for the fabrication of scenarios. Following we present a brief introduction of agent-based modeling simulation.

AGENT BASED MODELING SIMULATION (ABMS)

Agent-based modeling simulation (ABMS) is an M&S paradigm where the modeling focus is on autonomous, heterogeneous agents and their interactions. The primary purpose of ABMS is to generate macro (societal) level phenomena from the micro (individual) level behavior of agents. Among multiple fields for using ABMS one is modeling complex adaptive systems (CAS). Complex adaptive systems (CAS) are systems whose behavior is dependent on interacting subsystems and that behavior would fundamentally change if we remove any of those subsystems. As the name implies, CAS also adapt to their environment over time. Examples of CAS include a bee colony and human society. The literature advocates ABMS to modeling complex adaptive systems (Miller & Page, 2007). The advancement and propagation of technology within our society is another example of a complex adaptive system, thus ABMS can help representing and understanding parts of its complexity.

INTEGRATIONS BETWEEN ABMS WITH OTHER TOOLS

There have been some attempts to integrate ABMS into methodologies with different purposes. For example, Dal Forno and Merlone use ABMS *"to model artificial agents"* (Dal Forno & Merlone, 2012). The authors conducted experiments using ABMS to support grounded theory concepts. Ligtenberg et al. (Ligtenberg, van Lammeren, Bregt, & Beulens, 2010) used a roleplay approach to validate their ABMS. Collins and Hester (Collins & Hester, 2018) combined fuzzy cognitive maps with ABMS to help visualize the output of the FCM. There is evidence of achievement of integrative efforts modeling complex systems too. The most well-known example is systems dynamics, which was developed by Jay Forrester in the 1960s (Jay W. Forrester, 1961; Jay Wright Forrester, 1969; Jay W. Forrester, 1971). It is used to understand the flows and feedbacks within a complex system. System dynamics combines causal loop diagrams with continuous simulation. Systems dynamics has been connected to ABMS using a hybrid modeling approach (Lättilä, Hilletofth, & Lin, 2010; Mustafee et al., 2015).

A HYBRID MODEL: ABMS INTO TRM

A typical TRM incorporates future alternatives in its analysis but its ability to recognize emergence changes depends on the procedures for its implementation. This is due to the difficulties inherent to complex system representation. The purpose of this study is incorporate ABMS into a TRM as an attempt of bringing such complexity into a strategic planning process. This study has two objectives; 1) informing the ABMS process with contextual information coming from a TRM development, and 2) incorporating technological emergence result of the multiplication of effects into the strategic planning. We will explore a two-direction interaction bringing environmental information into the ABMS process and agency to the strategic planning. This integrative process; 1) defines the social actor, 2) build the TRM, 3) simulating agency, and 4) feedback into the TRM process. Figure 4 is a depiction of the general process.

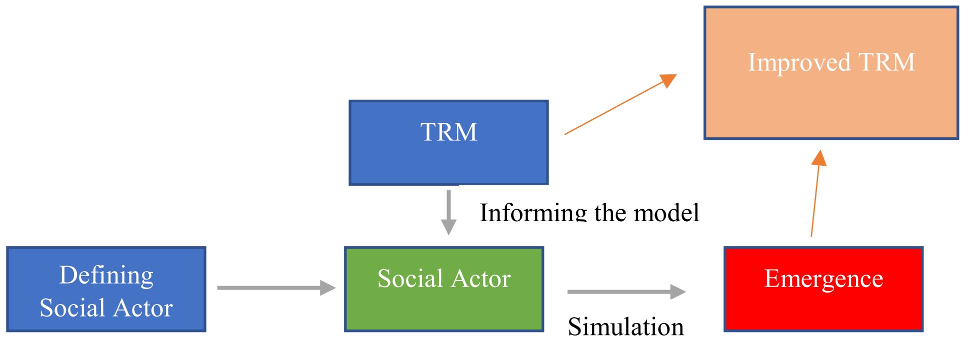

Figure 3. ABMS into a TRM process

Defining the social actor: The social actor in this work is the individual or group of individuals that decide whether using or not a particular technology. The social actor has different characteristics depending on the level of abstraction in the roadmap. Social actors exist at the strategic level, product/service level, and technological level. The social actor at the strategic level represents a group of interest. The different social actors in this level interact and form social trends with their decisions and preferences. The social actor at the product/service level is the producer of the concept – idea – product - service (CIPS). Similarly, the social actors at this level interact and compete for providing the best product that satisfies a societal need. The social actor at the technological level is user of a technology. Products compete to satisfy societal needs and present to the social actor at the technological level their alternatives.

Building the TRM: First, we will define the social trends that guide the TRM strategic-level analysis. The literature suggests multiple approaches to do it (Phaal et al., 2011; Phaal et al., 2003; Phaal et al.; Phaal, Farrukh, & Probert; Phaal et al., 2001; R. Phaal, C. Farrukh, & D. Probert, 2004; Phaal, Farrukh, & Probert, 2014; R. Phaal, C. J. P. Farrukh, & D. R. Probert, 2004; Phaal, Farrukh, & Probert, 2006). In this study, we will performed this analysis based on the systems thinking approach that Hester and Adams presented for defining a problem systematically (Hester & Adams, 2017). We will describe the way social actors in the strategic level define societal concerns as a result of balance of power and influence among them. Second, we will use linking grids as a tool that help us uncover the products and services that will satisfy societal priorities (Phaal et al., 2006). A linking grid is a the quantification of the level of satisfaction that the features of a specific product give to a social need (Phaal et al., 2006). Product-features respond to the priorities that social trends stablished and their alignment determines the survival of a company or organization. In the same way, we will use linking grids to bridge product and services features with technologies. We develop a contextual analysis of the technological environment and inform of the general characteristics of this market to the social actor at this level. At this level, the agent has operative and technical features.

Simulating agency: In contrast with a regular TRM process, the workshops will not only help to build the roadmap but also define the individual characteristics of the social actor in an ABMS process. Interactively, we inform the TRM process about emergence coming from the multiplicity of the agency into the three levels of analysis.

Feedback into the TRM: We simulate the interaction of social actors at the technological level of the TRM and inform the result of its agency into the TRM. At this point we will be able to explore different scenarios changing the characteristics of the agent and observing its implications at the strategic level.

CONCLUSIONS

In this paper we propose integrate ABMS into a TRM process. The purpose is operationalizing the emergence result of strategic decisions from the decision of a social actor regarding the use of a technology. We describe the procedure we plan to follow to carry on this integration process. We defined the general structure of the TRM and how develop it in a series of workshops. We also propose the inclusion of a feedback from the lower technological level of the

TRM using an ABMS. The feedback represents the emergence out of the decision an actor make among several technological alternatives. The integrative approach has two potential benefits; 1) a better-informed planning process, and 2) methodological improvement for both the TRM development and the ABMS. We believe that a systematic discussion of the environment around an ABMS exercise bring more richness and quality to the final model. Equally, we also believe that automating certain parts of a planning process it will improve the result of such process in a rapid changing environment. At this point we recognize that it is not easy for an organization invest time in a strategic exercise. Mainly because the people that needs to participate in a TRM process are heads of departments and coordinating agendas will be challenging. The quality of the process depends greatly of the quality of the information that the participants will bring to the discussion. We will encourage using only supported evidence for the workshops, but this is not always possible. Additionally, it is very important selecting a specific technology in a specific organization to carry on the experiment. This might be delicate information for an organization. Thus, we this study when we can have access to the strategic level of the organization.

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