Chapter 5
Technology Roadmap for Industry 4.0

Peiman Alipour Sarvari, Alp Ustundag, Emre Cevikcan, Ihsan Kaya and Selcuk Cebi

Abstract From both strategic and technologic perspectives, the Industry 4.0 roadmap visualizes every further step on the route towards an entirely digital enterprise. In order to achieve success in the digital transformation process, it is necessary to prepare the technology roadmap in the most accurate way. The intent of this chapter is to present a technology roadmap for Industry 4.0 transformation to facilitate the planning and implementation process.

5.1 Introduction

Technology road mapping is an important method that has become integral to creating and delivering strategy and innovation in many organizations. The graphical and collaborative nature of roadmaps supports strategic alignment and dialogue between functions in the firm and between organizations (IFM 2016). The technology roadmap process addresses the identification, selection, acquisition, development, exploitation, and protection of technologies (product, process, and infra structural) needed to achieve, maintain and grow a market position and business performance matching with the company's objectives (Toro-jarrín et al. 2016).

Rob Phaal is the pioneer and first developer of 'T-plan technology road mapping' in the 2000s (Phaal et al. 2001). This original work dedicated to the new methodology of taking a market-pull strategy, and gives a step-by-step framework on how to utilize road mapping in firms by using minimal resources. Consequently, his work became a primary framework for road mapping for both market pull and technology push approaches (Phaal et al. 2001). His approach is a tool for managers

P.A. Sarvari (✉) · A. Ustundag · E. Cevikcan
Department of Industrial Engineering, Faculty of Management,
Istanbul Technical University, Macka, Istanbul, Turkey
e-mail: alipoursarvarip@itu.edu.tr

I. Kaya · S. Cebi
Department of Industrial Engineering,
Yildiz Technical University, Besiktas, Istanbul, Turkey

A. Ustundag and E. Cevikcan, *Industry 4.0: Managing The Digital Transformation*,
Springer Series in Advanced Manufacturing, https://doi.org/10.1007/978-3-319-57870-5_5

and firms' policy makers to develop a roadmap very promptly, gives a chance to combine the development of technologies and activities for their exploitation and commercialization. However, many enterprises are incapable of launching roadmaps due to a lack of qualified staff for this process. In 2004, Phaal concluded that a qualified specialist in long-term planning horizon should handle the road mapping process (Phaal et al. 2004a).

Daim and Oliver (2008) define roadmap as a way to identify and decide upon trajectories to follow to reach future success, likewise as a traditional map guides travelers to their destination. The underlying principals usually relate to three specific characteristics, as it provides the corporation with an illustration of the current state, a desirable future state, and strategies to reach the future state (Phaal et al. 2004a). The key benefits of technology road mapping are given as follows:

- Establishing alignment of commercial and technical strategies
- Improving communication across teams and organizations
- Examining potential competitive strategies and ways to implement those strategies
- Efficient time management and planning
- Identifying the gaps between technology, market, and product intelligence
- Prioritizing the investments
- Setting competitive and rational targets
- Guiding and leading the project teams
- Visualizing outputs including goals, processes, and progresses.

Phaal et al. (2004b) identify eight types of graphical roadmaps according to the specific needs each one is a useful and recursive tool for strategic management. For study purpose, it was chosen multiple layers type, which is the most common format for a technology roadmap for the study of the current and future states related to three primary levels marked by Cosner et al. (2007): market, product, and resources. Market level describes current, and future customer needs accompanying with competitive strategies, regulatory environment, complementary product evolution, substitute products, disruptive innovations, and other factors. Strategic goals are stated as milestones or target dates for specific events; Product level documents performance and product features' evolution, new-to-the-company products (including services) and new-to-the-world products, and; Technology level describes expected R&D products, their availability dates, the driving factors for the R&D, and related information (Toro-jarrín et al. 2016).

Technology roadmaps can be used to facilitate the co-ordination of different staff functions. For instance, the widespread distrust between R&D and marketing units may be mitigated by means of a conjoint roadmap to which R&D contributes technological factors while marketing staff brings in a product-related perspective. Another field in which roadmaps prove to be helpful is that of competitive strategy. In this case, the interest groups involved are the company's marketing unit and its customers. The strategic utilization of roadmaps is principally reflected by the organization's announcement policy. A striking example of this can be recognized in the computer industry, where the Microsoft Corporation regularly succeeds in deterring consumers from purchasing a competitive product by explicitly

announcing the upcoming launch of a similar article (so-called 'vaporware'). Furthermore, technology roadmaps enable the coordination of inter- and extra corporate R&D activities. This function especially presents itself where huge cooperation or high levels of external procurement are expected. Eventually, individual companies have the option to join forces in devising a technology roadmap that supports their common orientation. This has happened very prominently in the semiconductor industry (Erol et al. 2016).

In today's business, Industry 4.0 is driven by digital transformation in vertical/horizontal value chains and product/service offerings of the companies. The required key technologies for Industry 4.0 transformation such as artificial intelligence, internet of things, machine learning, cloud systems, cybersecurity, adaptive robotics cause radical changes in the business processes of organizations. The challenges for Industry 4.0 transformation are determined as:

- Lack of knowledge about technologies and their opportunities
- Uncertainty about the benefits of technology investments on products and processes
- Lack of knowledge about customer demand regarding new products and business models under industry 4.0 vision
- Limited human and financial resources
- Difficulties to spot the starting point and milestones of planning horizon
- Need for efficient portfolio management for technology investments
- Requirements for prioritization and scheduling of new product and process projects
- Allocating the limited resources to the projects and collaborating with reliable partners
- Lack of communication about the benefits of the Industry 4.0 transformation projects through the organization.

Therefore, the strategy followed by a company while adopting new technologies to its processes and products has a critical importance. As the first step, the organization has to develop a roadmap which is a complex long-term planning instrument that allows for setting strategic goals and estimating the potential of new technologies, products, and services (Vishnevskiy et al. 2016).

The objective of this study is to facilitate to managers, policy makers and practitioners the creation of a technology roadmap for Industry 4.0 transformation. This chapter proposes a comprehensive framework for Industry 4.0 road mapping. The main goal is to overcome the challenges and difficulties confronted by the companies in the digital transformation process.

5.2 Proposed Framework for Technology Roadmap

In a promptly changing world, to visualize the future is not only an additional tool for strategic planning but a necessary practice for every company. Rohrbeck and Schwarz (2013) emphasized that the early acknowledge and visionary anticipation

of the technological potential play a pivotal role in a business environment which is characterized by the improvement of competitiveness. They also observed that ignoring changes in a globalized world often results in losing opportunities or failing in responding threats. For Makridakis (Godet 2010) the role of visioning the future is to provide managers and government policy maker's different ways to comprehend the future and help them have a whole perception of possible implications of social and technological changes.

A "roadmap" empowers whoever in the industry to simply understand each move and what decisions need to be done, who needs to make them and when. This procedure is decoded into a project plan, specifying the characteristics of work in each of the associated stages of formation. In our proposed framework in Fig. 5.1, the strategies and key technologies are defined in the first phase of the roadmap, subsequently, in the second phase, development of the new products and processes is conducted.

In the new product and process development phase, ideas are generated at first, the generated ideas are evaluated and some potential ideas are selected for the implementation. Considering the natural constraints like budget limits, partnership policies and inadequate human resources just some of the chosen ideas can be projected in shape of one or several portfolios. Project prioritization usually has been conducted based on its benefits and added values. Scheduling which is the time-horizoned framework of Industry 4.0 roadmap has visualized the technologies, targets, processes and progress levels. The last step of road mapping is the implementation, which is settling down the defined product and process projects, and dynamically reviewed compared to the updated ideas, new products, new key technologies and better processes. All steps of proposed road mapping flow are going to be described in details via following sections.

5.2.1 Strategy Phase

A strategy is defined in a time-based plan and portrays where an industry is, where it needs to go, and how to get it there. Strategy phase of the roadmap is a collaborative procedure to planning. In the strategy phase, the evaluation of the enterprise digital maturity to set clear targets for the next years (based on the time horizon) is the first step that one should take into account during preparing the Industry 4.0 roadmap. Many industrial capabilities have already begun digitizing their business, but often the process has started in the low levels of the organization. Taking the time to evaluate the maturity level in all areas of Industry 4.0 can help to understand what strengths are possible to build already on, and which systems/processes are needed to combine into future solutions. Simultaneously to think about where an organization wants to go in the future, one should consider what the organization could gain by co-operating with clients, suppliers, technology partners and even competitors, without restricting the vision based on current limitations. The focus should be beyond the technical details and estimates the

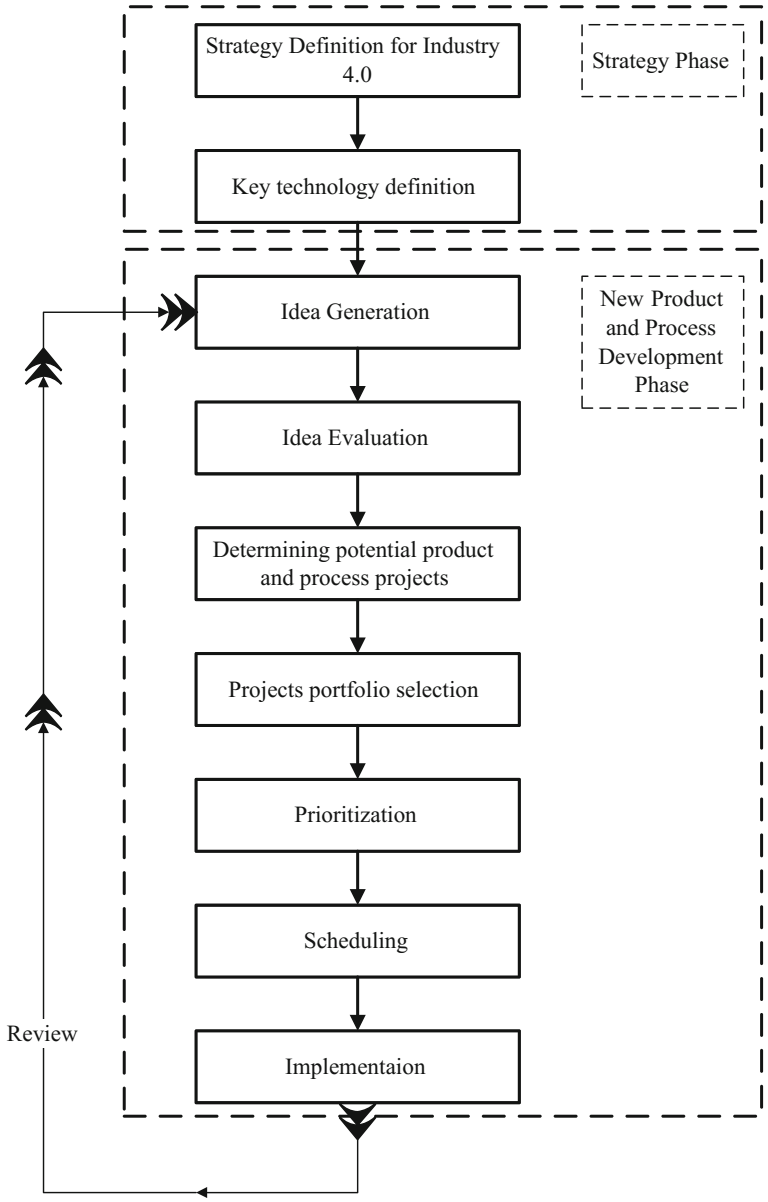

Fig. 5.1 Proposed technology roadmap for Industry 4.0

impacts of new applications on organization's value chain. The roadmap will need to consider future changes in customer behavior and how the organization relationship with them will change. Driving from the current to the future desired state will demand precise steps and a clear prioritization.

Strategies answer the question of what has to be done to achieve the desired outcome (Osterwalder and Pigneur 2010). From another side, the technology development and market demands accelerate changes in the world. From the strategic perspective, it is frequently found that technology innovation is a key advantageous factor for performance improvement and survival of the enterprise, besides it is a determinant factor for the sustainable economic growth of nations and quality life improvement of their people (Keupp et al. 2012). According to Rohrbeck and Schwarz (2013), firms suffer blindness caused by focusing mostly on the inside of the company and reinforcing practices that made the company successful in the past thus, it becomes evident that firms need to dedicate efforts to look outside the company and to be aware of the coming changes. In another word, the capacity for bringing value to the customer is strongly related to the technology development. Furthermore, before new product and process development phase, the key technologies having strategic importance for the company should be determined meticulously.

5.2.2 New Product and Process Development Phase

The new product and process development phase allows sketching goals and projects considering different principles and constraints on separate layers against a shared vision. For our purpose, we use a distinction into three technical perspectives: technology constraints (budget and partnerships), goals (saving, revenue, risks) and projects. Three layers represent these perspectives. Figure 5.2 depicts the three layers of portfolio selection and project prioritization.

At this moment, the generated ideas are selected by experts based on the products and processes feasibility dimensions. After listing the potential projects, the selection stage of the projects portfolios is fulfilled. Prioritization stage is conducted considering saving and risk factors for new process development projects, also the revenue and risk factors for new product development projects. Figure 5.2 illustrates a flow of matrices in terms of project selection and forming portfolios.

It is worth to note that the optimal portfolio should lie on the Efficient Frontier curve which constitute saving and revenue as the vertical dimension whereas the horizontal dimension reflects the risk. The chart shown on Fig. 5.3 demonstrates how the optimal portfolio forms. The optimal risk portfolio is normally defined to be around in the center of the curve since as one goes higher up the curve, one takes on proportionately more risk for a lower incremental return. Oppositely low risk/low return portfolios are pointless since you can gain a similar return by investing in risk-free assets. You can pick how much volatility you can bear in your portfolio by selecting any other point that falls on the efficient frontier. So your true selected portfolio will give you the maximum saving and revenue for the percentage of risk you are planning to accept. Briefly, the portfolios above the efficient frontier curve are impossible and the portfolios below the efficient frontier are not efficient because for the same risk one could achieve a greater return.

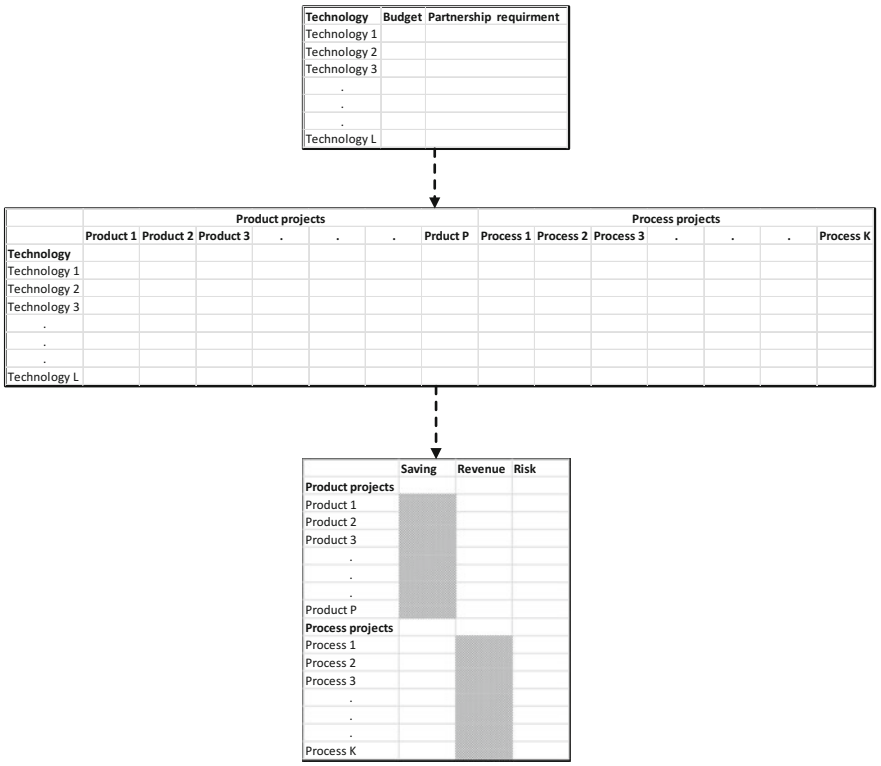

Fig. 5.2 Prioritization matrices for product and process projects

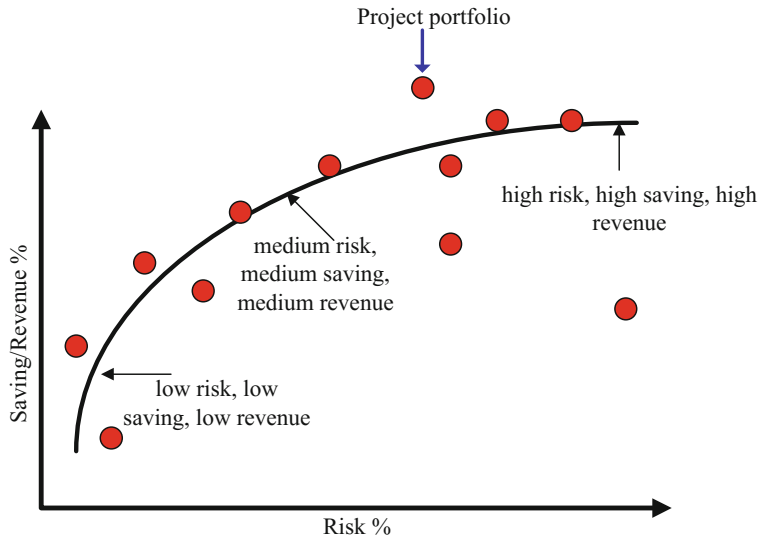

Fig. 5.3 Efficient frontier curve for portfolio selection

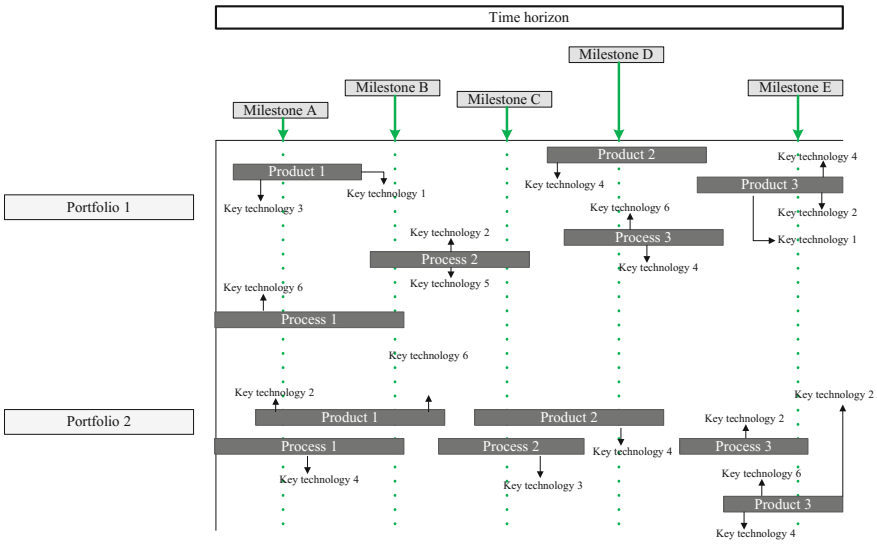

Fig. 5.4 An exemplary scheduled Industry 4.0 roadmap for two portfolios

Scheduling is the next stage of the mapping defining milestones and projects statuses. The output of this stage is a timely ordered and multi-perspective map of the overall approach towards the envisioned Industry 4.0 concept that builds the strategic frame for concrete actions. The time horizon for the accomplishment of the Industry 4.0 vision settles whether a company takes a revolutionary strategy versus an evolutionary strategy. Figure 5.4 illustrates an exemplary scheduled roadmap for twelve projects in the shape of two portfolios with specified milestones and engaged key technologies in a strategically defined time horizon.

Each box in the roadmap represents a state or project on the way to the ultimate Industry 4.0 vision. Additionally as well, a strategy to reach the goal is shaped into milestones. Milestones are progressed percentages of savings, budget usages, terminated projects, applied technologies, etc. The required key technologies represented on each box of projects. The time dimension is indicated by a rough time-frame or a concrete date depending on the overall time horizon of the company.

5.3 Conclusion

Considering a globalizing world, the need to implement development strategies that can sustainably guarantee the competitiveness of companies is the main issue. It is in this context that Industry 4.0 roadmap presents itself as a visually pictured clear path to boost the competitiveness of companies. The Industry 4.0 roadmap gives an

overview of the current situation of the company and the perspective situation to be reached in a time horizon. A genuine prediction of Industry 4.0 has created unique ideas shaping products, processes, and opportunities in terms of defined targets and milestones. In this regard, the continuously evolving key technologies and solutions are an undeniable part of fulfilling the vision of the designed roadmaps. This chapter tried to present a comprehensive Industry 4.0 roadmap framework covering the strategy, new product and process development phases. The proposed roadmap design flow covers a broad range of strategic planning to implementation of the defined visions to facilitate building manufacturers' Industry 4.0 roadmaps. With reminding the criticality of review and feedback concepts of the dynamic structure of the cycle between idea generation stage and the implementation step, the chapter concludes that it is important that company managers understand and follow presented above core principles for not facing with difficult replacement decisions.

References

Cosner RR, Hynds EJ, Fusfeld AR, Loweth CV, Scouten C, Albright R (2007) Integrating roadmapping into technical planning. Res Technol Manag 50(6): 31–48

Daim T, Oliver T (2008) Implementing technology roadmap process in the energy services sector: a case study of a government agency. Technol Forecast Soc Chang. 75:687–720

Erol S, Schumacher A, Sihn W (2016) Strategic guidance towards Industry 4.0—a three-stage process model. In: International conference on competitive manufacturing

Godet M (2010) Future memories. Technol Forecast Soc Chang 77:1457–1463

Keupp MM, Palmié M, Gassmann O (2012) The strategic management of innovation: a systematic review and paths for future research. Int J Manag Rev 14:367–390

Osterwalder A, Pigneur Y (2010) Business model generation: a handbook for visionaries, game changers, and challengers. Wiley, New York

Phaal R, Farrukh C, Probert D (2001) T-plan: the fast start to technology roadmapping: planning your route to success. Institute for Manufacturing, University of Cambridge, Cambridge, UK

Phaal R, Farrukh C, Probert D (2004a) Customizing roadmapping. Res Technol Manag 47(2):26–37

Phaal R, Farrukh CJ, Probert DR (2004b) Technology roadmapping—a planning frame-work for evolution and revolution. Technol Forecast Soc Chang 71:5–26

Roadmapping at IfM—Institute for Manufacturing, University of Cambridge. Retrieved from http://www.ifm.eng.cam.ac.uk/ifmecs/business-tools/roadmapping/roadmapping-at-if

Rohrbeck R, Schwarz JO (2013) The value contribution of strategic foresight: insights from an empirical study of large European companies. Technol Forecast Soc Chang 80:1593–1606

Toro-jarrín MA, Ponce-jaramillo IE, Güemes-castorena D (2016) Technological Forecasting & Social Change Methodology for the of building process integration of Business Model Canvas and Technological Roadmap. Technol Forecast Soc Chang 110:213–225

Vishnevskiy K, Karasev O, Meissner D (2016) Technological Forecasting & Social Change Integrated roadmaps for strategic management and planning. Technol Forecast Soc Chang 110:153–166