Innovation Driver New Production Technologies: Strategic Planning using Technology Roadmapping

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Abstract: As innovation cycles are becoming shorter and technological progress faster, the need for reliable decision support for product and production planning is rapidly gaining crucial importance. To this aim, strongly innovation-driven industries like automotive use roadmaps relating products and technologies to a timeline from a specific company's viewpoint. Technology-driven manufacturing companies are struggling to apply technology roadmapping in a transparent, traceable and risk-minimizing way to plan their future production technology and competence needs. This paper points out the necessity of a holistic and integrated approach to using this instrument to help prepare organizations for new manufacturing processes and technologies in a timely and successful manner. It investigates the state of the art of technology roadmapping for strategic production planning, and derives necessary fields of action in the context of an industrial research and innovation project.

Keywords: Strategic Foresight, Strategic Agility, Technology Roadmapping, Innovation Management for Manufacturing, Strategic Production Planning, Roadmapping Process, Decision Support

1 Introduction

Manufacturing industries are confronted with exceptional challenges in period which is frequently called the "fourth industrial revolution". Modern manufacturing paradigms such as Added-Value Manufacturing and Knowledge-based Manufacturing are mainly characterized by the fact that modern production is increasingly driven by integrated information technology (IT) systems, rendering manufacturing systems more autonomous, flexible and configurable. At the same time, the megatrend environmental sustainability is driving new manufacturing technologies and processes at a speed that has never been experienced before. Additive manufacturing and lightweight materials processing are only two representative examples for those drivers which are confronting manufacturing industries with new and complex challenges.

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More than ever before these industries will have to invest early in the building up of know-how and infrastructure to implement manufacturing processes, and adapt them timely both to the rapid technology development and ever changing product requirements. Industries are therefore looking for tools helping them plan production technology investments timely and reliably. The challenge is to prepare technology development as good as possible, to anticipate changes and to implement actions timely in addition to cover the ground. However, industrial organizations seeking to drive product, service and process innovation also by their manufacturing technologies and processes are looking for a methodological support for what we want to call strategic production planning (SPP) in the following.

This article investigates the relevance and use of technology roadmapping (TRM) for this purpose from the particular point of view of a large German tier-1 automotive supplier. Section 2 explains the requirements to a production technology planning instrument from a practical point of view, with a particular regard on related innovation management aspects. Section 3 presents a bibliometric analysis based literature review on TRM and identifies the particular challenges linked to the use of this instrument for SPP. Section 4 provides an insight into an industrial research project introduced in this paper that has been launched with the aim to fill some major gaps that currently render TRM difficult to use for production technology planning. Finally, the paper concludes by a summary and an outlook on the objectives of the industrial research project.

2 Production technology planning needs

In order to explain the challenges associated with production technology planning in the context of innovation management, we want to point out the necessity of a methodological support for SPP in industrial organisations seeking to drive innovation also by their manufacturing technologies and processes. These organisations aim at integrating production technology planning into their innovation management processes. Innovation management in production wants to make the production fit for the future. In order to capture the numerous dependencies this process has, it makes sense to distinguish between the activity groups related to strategic production planning, the actual content of SPP and the specific innovation areas in the SPP (Figure 1).

In the SPP, many assets and activities are associated with the innovation planning of a holistic production, especially the trend management and hence the consideration of internal and external requirements. Many external and internal inputs that influence the production have to be reflected adequately. There are aspects of the internal requirements coming from the production constraints, foreign locations, strategy, investment, and so on. Moreover the proper handling of trends in the production is critical, because trends often refer only to the product without drawing conclusions about the manufacturing of these products. In addition to that, the active procurement and capitalization on external inputs (e.g. external analysis of production topics) is often not carried due to lack of resources made available to this aim. Mostly this is the consequence of poor management attention to pro-active innovation management for the production. A key question is therefore how to guarantee an optimal SPP to identify fields of action in the production in the context of production specific trends.

In all the mentioned activities and especially in content of SPP, there is a need of interaction with many sub-systems such as machine planning, production system design, international location and layout planning. Furthermore activities regarding research, strategic operational business, development, innovation management, etc. have to be agreed upon the stakeholders. In every step of SPP various stakeholders within the production and from neighbouring areas have to be involved systematically. At this stage the SPP is methodologically supported by strategic considerations in different dimensions. Tools such as the portfolio tool (do we produce and assemble internally or externally?) and the roadmap (how do we produce?) can help in the SPP. The technology roadmap hedges a suitable use of production technologies, e.g. to achieve the goal of an optimal degree of automation in the production and the development of skills and competences in the production whereas a production portfolio can improve the connection between foreign locations and make or buy decisions concerning production planning aspects.

On the operational level an appropriate idea management with respect to an adequate trend management is important to ensure the right use of strategic tools with the right topics. Innovations in the SPP can happen especially on the basis of the active management and implementation of new production technology ideas that are dynamically positioned in the roadmap according to a defined process and taking into account clearly defined criteria (e.g. the technology's alignment with the company strategy, its core competencies and corporate image). Considering the example of the trend topic lightweight construction, ideas have to be generated to find materials, technologies and related production methods that lead to weight reduction. This, however, also implies to think about how and when to build up methodological competences around these topics, as well as material expertise.

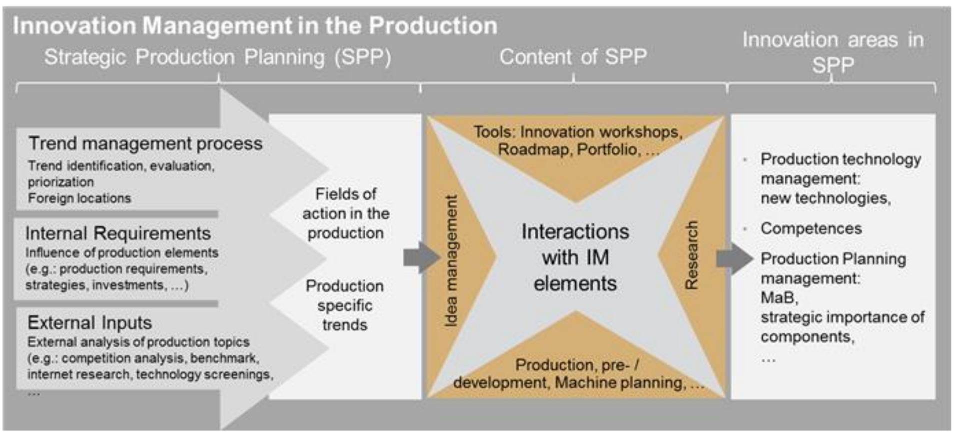

Figure 1 Strategic production planning as a fundamental element of innovation management in production (Flatscher, Riel & Kösler 2014)

Consequently innovation in the SPP is successful if it succeeds in getting the organization engaged in right topics with the right actions at the right points of time. In that manner the SPP ensures innovative approaches such as the suitable use of production technologies, dealing with new technologies, building of competences and skills, as well as an innovative production planning. In all mentioned findings dependencies between SPP elements and tools exist and are complex.

3 A literature review of technology roadmapping

TRM is an effective tool for technology planning and coordination which fits within a broader set of planning activities (Garcia & Bray 1997). Motorola was the first to publish about the use of a technology roadmap from the viewpoint of a practitioner (Willyard & McClees 1987). As a further industrialist, Philips Electronics confirms the technology roadmap as tool for better integration of business and technology strategy (Groeneveld 1997). Over the last few years, roadmapping has been a gaining momentum as a strategic management tool for organisations to better adapt themselves to modern marketplaces (Gerdsri & Vatananan 2011) or even to strengthen the competitiveness in aligning the development of several technologies (Schuh & Orilski 2007).

There is a set of different roadmaps with different purposes such as forecasting, planning, and administration (Lee & Park 2005; Gerdsri et al. 2013; Vatananan & Gerdsri 2012; Buczacki 2012). The most generic roadmap consists of layers such as market, product and technology spanning over a horizontal timeline. In these layers, the evolution of the competition, markets, products, technologies as well as the relationships between these factors are depicted (EIRMA 1997). The synchronisation of all relevant planning levels leads to a holistic, aligned technology planning. However, there is no methodological support of the consideration of interdependencies between planning objects and no dynamic, transparent visualisation for relevant planning situations (Orilski et al. 2009). The formalised roadmap process is composed of the three phases: preliminary activity, development, and follow-up activity (Willyard & McClees 1987). The architecture of a roadmap consists of a planning horizon and key milestones (Phaal et al. 2003a).

A systematic literature review published by Carvalho et al. shows that the principal academic journals that discuss TRM are in the field of "Technology Forecasting and Social Change" and "Research-Technology Management". Thus the use of roadmapping for forecasting plays an important role, largely because of the alignment between strategic objectives and technology management (Carvalho et al. 2013). Furthermore it is possible to anticipate, identify, and confirm changes in industry and technology to spot market, technology and research gaps (Garcia & Bray 1997; McMillan 2003; Phaal et al. 2003b; Garcia 1997; Paci 2007). The incorporation of knowledge of patterns of technological evolution into technology roadmaps makes it possible to detect opportunities for innovation and possible market limitations (Rinne 2004). A crucial condition hereby is an adequate technology assessment when creating the roadmap (Herrmann et al. 2009).

A major objective of the TRM process is to come up with a support for technology investment decisions. Often it is not clear which alternative to pursue, how quickly a new technology will be adopted on the market, or when there is a need to coordinate the development of multiple technologies (Garcia & Bray 1997). In this case roadmapping provides information to make better technology investment decisions in identifying critical technologies and gaps and therefore ways to leverage R&D investments (Ahlqvist et al. 2013). Linking R&D investment strategies to business leads to strategic technology alignment roadmapping (Gindy et al. 2009; Gindy et al. 2008).

Ioannou et al. insist on the importance of the fact that for TRM to be successful, the strategic decision-making process has to be a collaborative one (Ioannou et al. 2009). By its very nature, roadmapping is a mediating and networking approach (Miller & O'Leary 2007). The activation of network can be the integration of supplier in the roadmap as innovative collaborative networks building (Goenaga & Castellano 2008) or a cross-functional approach to product and technology planning and vision building (Lee & Park 2005) or the ongoing coordination between the corporate laboratories and the business units (Kappel 2001). Because of many affected people there are synergies among team members from different departments (Gerdsri & Vatananan 2007) and more members including both technical and commercial functions such as R&D, product development, manufacturing, marketing, finance, and human resources (Albright & Kappel 2003; Phaal et al. 2003b).

In considering the roadmap as a networking approach the outcome is a consensus building process, which connects an expected future (descriptive) with a desired future (normative) (Zweck & Holtmannspötter 2009). This consensus building succeeds because of the possibility in roadmapping to create a breakdown from a master business roadmap all the way to a technology introduction plan on the strategic level. These plans are further refined at the tactical level, and finally completed into separate project plans for implementation (Hakkarainen 2006).

With the adequate management attention in the roadmapping process, the roadmap team will be motivated to do good work by considering several options, addressing management's key concerns, and justifying their positions with a clear rationale (Kappel 2001). Their participation will increase because it is known that the output would be used in funding decisions, noting that participants and the attention of decision makers were involved in the roadmapping effort (Kappel 2001). Thereby the roadmap permits the investigators to then gather evidence about key decisions and their consistency (Kappel 2001). This is especially important for decision aids to improve the coordination of activities and resources in increasingly complex and uncertain environments (Kostoff & Schaller 2001). TRM must therefore deal with challenges of knowledge and collaboration (Ioannou et al. 2009). In order to make sure that both the operational and strategic technology decision making succeed it is important to provide a framework to structure diverse information of simultaneously explicit data and the tacit knowledge (Petrick & Provance, 2005).

As a decision support instrument, roadmapping is also a means of risk identification, quantification, and mitigation. A so called risk-aware roadmapping supports an appropriate treatment of uncertainty and risk and delivers the identification, resolution and communication of uncertainties and risks. This includes a conscious and explicit effort to address uncertainty and risk and the necessary mitigation steps and procedures (Ilevbare 2014).

One particular important aspect of technology planning is the sourcing of new technologies in terms of building up of new competencies to bridge foreseeable technology gaps. Hereby it is necessary to align technology and competencies within an overall roadmap (Gokhale & Myer 2007), which gives the opportunity for a company to identify new core capabilities and competencies to focus on (Barker & Smith 1995). As a dynamic strategic practice it constructs and fosters relevant future-oriented knowledge that builds on the systemic understanding of the 'grand challenges'. This knowledge will be linked with actual strategic practices in the organization converting future information towards future knowledge (Ahlqvist & Koch 2013), arising structural relationships among science, technology, and applications (Kostoff & Schaller 2001). In supporting the strategic business planning and thus the evaluation of different opportunities or threats, gaps are identified at the business level, by comparing the future vision with the current position, and strategic options explored to bridge the gaps (Phaal et al. 2004). An integrated TRM methodology enables the management to define its technology requirements, taking into account financial and other issues, to assess proposed technology projects against these requirements and to create a balanced technology project portfolio. The thereby gained improved clarity and transparency of decisions makes it easier to justify the assignment of resources to technology assessment (Gindy et al. 2006).

As a logical path creator from strategy to implementation roadmapping provides a treatment in strategic, tactical, explicit and operational tier (Hakkarainen 2006). Thereby a master roadmap can summarizes an entire strategy of a business securing highly sensitive and confidential information and generalization of more detailed and focused maps. Specific roadmap responsible persons have full freedom and consequent responsibility to plan and execute their developments and actions, provided they do not contradict, or have side effects on, the master roadmap level (Hakkarainen & Talonen 2012). Thereby it simultaneously captures explicit data and the tacit knowledge (Petrick & Provance 2005). Thus roadmapping offers a process to support a holistic technology management. There are early activities like technology foresight and strategy development as well as controlling of individual projects until they fully impact the company's profitability (Lischka & Gemünden 2008).

While the roadmap is fairly simple in structure and concept, its content is the result of processes that involve considerable levels of complexity detail (Phaal et al. 2001). Implementing these processes and measuring their performance represents a huge challenge for organizations. They are compelled to evaluate the technique's value and its return on investment in terms of the effectiveness of the outcomes. This includes quality control of data and information used in the TRM process (Vatananan & Gerdsri 2012).

Another challenge is the difficulty to keep the roadmapping process 'alive' on an ongoing basis (Vatananan & Gerdsri 2012; Lee et al. 2012). Approaches are needed to knowing how and when to review and update a roadmap and how to effectively maintain and improve the roadmapping process once it is integrated into day-to-day operations (EIRMA 1997). There is a lack of practical guidelines for all roadmapping steps, and in particular for the regular update of an already implemented roadmap (Garcia & Bray 1997; Phaal et al. 2004; Farrukh et al. 2001; Lee et al. 2007).

A key success factor is the establishment of a collaborative network to ensure a dynamic 'alive' roadmapping process. This is typically a difficult task that requires a lot of efforts (Goenaga & Castellano 2008). There are many surveys investigating which stakeholders to involve in roadmapping and how (Vatananan & Gerdsri 2012; Kappel 2001; Gausemeier et al. 2012). They point out that stakeholders are often not well aware of the usefulness of the roadmap and sometimes even resist following because of the negative consequences for the degree to which the technology roadmap is used and continuously maintained (Lee et al. 2012; Nakamura et al. 2006).

4 Towards a systematic process-based approach to roadmapping

This last finding pointed out in the previous section summarizes the major conclusions that we can draw from our literature analysis of TRM: The theoretical body underlying the TRM practice is surprisingly sparse, in general and in particular for production technology. Only very few articles addressing the topic of a systematic approach to planning investments into and deployment of modern manufacturing technologies in a way that industrial organizations get an actionable guidance to deploying production technology planning successfully. Most of the articles use a roadmap as a tool to visualize or manage individual targets such as trends and research challenges in sustainable manufacturing and not to provide methodological approaches to support firms to be flexible in trend handling in the holistic production. Nakamura et al. argue that an academic approach based on a theoretical foundation is necessary to fill the gaps that exist between the potential of TRM and its actual usefulness in existing organisations (Nakamura et al. 2006). So far, the evolution of roadmapping as a strategic decision support tool has been led by management practice rather than by management theory (Phaal et al. 2005; Holmes & Ferrill 2005). Only Lichtenthaler provides a contribution to opening up TRM to take into account the increasing importance of external technology commercialization and thereby establish successful strategic technology planning processes in the context of open innovation (Lichtenthaler 2008).

Based on the major conclusions above and in the context of a recently launched collaborative research project, we are addressing the challenge of how to approach strategic innovation planning systematically from a production technology point of view and designing and investigating a roadmapping process whose specific objective is to support SPP in close cooperation with the strategic product and procurement planning. This roadmapping process consists in three steps from megatrends towards actions/project sheets. The concretization level increases towards the actions. Concrete actions are than visualized in a roadmap. The process is on a rolling one year basis. At the heart of this approach is the systematic and regularly collaboration of key stakeholders from different organizational units and departments (research and development, production technology, procurement, site planning, etc.) in moderated ideation workshops. The workshops take place regularly every 3 months and different moderation techniques are applied depending on the concretization level of the process stage. In the whole innovation management in the production, shown in Figure 1, and especially in the initial stage of trend management the open way of problem solving proposed by Geschka, can be used as fundamental process element. The first divergent thinking step identifies trends with a very wide open angle of view. Hereby out-of-the-box thinking is the major objective. Then followed is a consolidation phase where methods for finding convergence are applied. Here, the major objective is to process relevant trends in a way that topics can be prioritized and production specific trend can be identified (Geschka 2010).

5 Conclusion

Production Technology Planning is exposed to numerous interdisciplinary dependencies especially to the product planning, which makes the process complex. In this context strategic roadmapping is an important and common used means for product and technology planning in the several industry sectors, most notably the automotive sector. Unfortunately roadmapping of products and product technologies in common practice is often done with only few links to the roadmapping of production and production technologies, which leads to the fact that companies perform sub-optimally with respect to the speed and timeliness of build-up of new expertise such as new production technologies. The ever increasing speed of technological progress and changes determines a huge potential of improving competitive advantages by mastering the integration of production technology planning with product / service planning better than competitors do.

One key contribution of this paper is the revealed need for such activities, and the investigated state of the art of TRM as a facilitating tool for strategic production planning. Our key finding of the bibliometric analysis based literature review on TRM is that very few publications give practically usable instructions and/or best practice experience reports of how to set up, implement and deploy roadmapping successfully. In particular, we could not find explicit treatment of TRM for SPP in literature. Given that roadmaps are an important and widely used means of product and technology planning, we are convinced that roadmapping can also provide a considerable support in strategic production planning.

The recently launched collaborative industrial research project introduced in this paper aims at establishing a systematic TRM process for SPP on a pilot project level. Beyond the roadmapping process itself, a particular challenge will be to extend the scope from pure technology planning to an integrated strategic planning of technologies and their associated competencies, infrastructures, and deployment in the organization and the products and services delivered. At the heart of this supportive approach is the systematic collaboration of key stakeholders from strategic product and procurement planning in moderated ideation workshops. These workshops take the involved stakeholders from technological, societal, economical and ecological megatrends to their specific impact on the company from the viewpoint of production technology in relationship with products and strategic company evolution objectives.

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