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Stakeholder integration for the successful product–process co-design for next-generation manufacturing technologies

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ABSTRACT

In Industry 4.0, manufacturing technology has a huge potential of becoming a key facilitator for groundbreaking innovations of products, services, and processes. To exploit this potential, industrial organisations have to transform legacy structures and processes in integrated organisations uniting experts from design, manufacturing, procurement, etc. This research accompanies one of the biggest automotive tier-1 supplier along this transformation. The key objective is to find and analyse ways of integrating different trades in design workshops aimed at the long-term strategic planning the investment in approaches to integrating design, manufacturing, and procurement departments for leveraging Industry 4.0 potentials.

1. Introduction

Manufacturingindustries are confronted with exceptional challenges in an era which is frequently called the "Fourth Industrial Revolution". Modern manufacturing paradigms such as Added-Value and Knowledge-based Manufacturing are mainly characterised by the fact that production is increasingly driven by integrated information technology systems, rendering manufacturing systems more autonomous, flexible and configurable. Megatrends are driving new manufacturing technologies and processes at a speed never experienced before. Additive manufacturing and lightweight materials processing are only two representative examples for technologies confronting manufacturing industries with new and complex challenges. More than ever before these industries have to invest early in know-how and infrastructure to implement production technologies, and adapt them timely both to the rapid technology development and the ever changing product requirements. Industries are therefore looking for methods and tools helping them plan such investments systematically, reliably, and with a holistic view.

This article proposes a systematic yet highly creative process for strategic production planning (SPP) that is entirely based on concepts of integrated design [1]. Its objective is the integrated design of technology roadmaps (TRM) which are an established decision support tool for long-term technology planning in industrial organisations. Section 2 explains the context, the research objectives and methodology. Section 3 summarises the state of the art of SPP with a particular regard to TRM. Section 4 presents the integrated design principles based approach to SPP that we have developed. Section 5 elaborates on the validation of this approach in the context of one of the worldwide largest automotive tier-1 suppliers in Germany. Section 6 concludes with a summary of the key contributions and an outlook.

2. Target and methodology

The objective of this research is to elaborate a systematic and actionable approach that helps industrial organisations plan their future investments and activities in modern production technology and the related processes and organisations. Having led and participated in numerous technology planning sessions, our fundamental hypothesis is that strategic production planning in an Industry 4.0 context has a lot of characteristics in common with creative integrated design processes for new products, services and processes (NPD): [2]

(1) the outcome of the planning is unknown at process start,
(2) the artefacts to be designed are highly interdisciplinary in their nature thus requiring experts from several different trades to actively participate in the process,
(3) only a relatively small number of key requirements to the process and the final outcome are given at the beginning, whereas the identification and formalisation of requirements and constraints is part of the design process,
(4) The outcome of the process is subject to evolution, driven by requirements changes as well as the changing context.

Hence, our quite natural idea and assumption is to find a means to carry out SPP as a creative integrated design process, bringing together experts from diverse organisational units. To validate this hypothesis based on published and own experiences, we designed a novel structured ideation process taking into account the constraints we face in stage-gate process driven organisations, and for the particular objective of SPP, and applied it in a pilot project at an automotive tier-1 supplier over one year.

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3. Key findings about the state of the art

In order to analyse the state of the art of SPP with a particular regard to TRM, we have carried out a systematic literature review using bibliometric analysis facilitated by CiteSpace. We can only present very few key insights of this analysis here. Motorola was the first to publish about the use of a technology roadmap as a tool for better integration of business and technology strategy [3]. Over the last few years, roadmapping has been gaining momentum as a strategic management tool for organisations to better adapt themselves to modern marketplaces [4]. While the roadmap is fairly simple in structure and concept, its content is the result of complex processes. Implementing these processes and measuring their performance represents a huge challenge for organisations. There is a lack of practical guidelines for all roadmapping steps, in particular for the regular update of an already implemented roadmap [5]. 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 [6]. Thus, roadmapping has to take a mediating and networking approach which can happen by the integration of suppliers in the TRM process, a cross-functional approach to product and technology planning and vision building, as well as the ongoing coordination between corporate laboratories and business units [7]. Team members from different departments including both technical and commercial functions such as R&D, product development, manufacturing, marketing, finance, and human resources are involved in a consensus building process, which connects an expected future (descriptive) with a desired future (normative) [8]. Tolio et al. confirm this by investigating the co-evolution of products, processes and production systems in order to address challenges like new regulations, new materials, technologies, services and communications [9]. Putnik et al. discuss the scalability in manufacturing systems design and operation, using advanced and emerging design and management approaches and information and communication technologies to support their effective and efficient deployment in practice [10]. None of these articles, however, deal with a systematic and actionable approach to implement TRM for SPP in an industrial organisation.

Holmes et al. confirm our own finding that the evolution of roadmapping as a strategic decision support tool has been led by management practice rather than by theory [11]. Publications covering TRM are in general focused on explaining the value of roadmaps as decision support tool and the typical difficulties encountered during their deployment, rather than on practically usable approaches and/or best practice experience reports. In particular, we could not find any explicit treatment of TRM for strategic production planning in literature. Neither could we identify any collaborative or integrated design based approach to TRM and SPP in general. This represents a real problem for industries struggling to prepare themselves timely for the challenges, opportunities and risks that the fourth industrial revolution is about to bring along [12].

4. A design process for strategic production planning

In the context of a clearly structured and stage–gate process driven organisation, the entry challenge of executing a SPP project as a creative design process [13] is to propose a clear design process structure allows for a high degree of dynamics at the same time. Our approach is based on the model of problem solving published by Geschka [14] (Fig. 1).

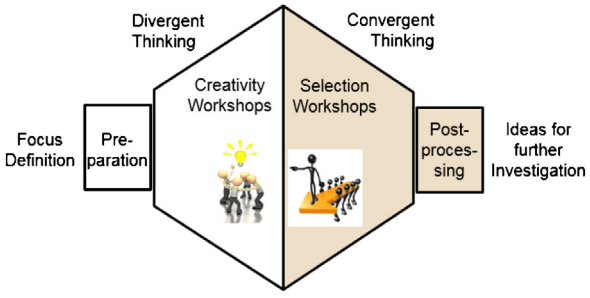

Fig. 1. Basic ideation process model based on Geschka [14].

The fundamental idea underlying this model is that in an integrated design process, the involved stakeholders shall run through a series of phases of divergent and convergent thinking. Every phase of divergence is a phase of idea generation and out-of-the-box thinking related to topics defined and prepared before. Experts from different domains work together in moderated creativity workshops, where the moderator's principal function is to help participants open up their minds to be able to get out of their boxes (i.e., contexts). The numerous ideas have to be consolidated and evaluated in the subsequent convergence phase whose principal objective is to decide how to proceed with each single idea generated during the previous phase. In moderated idea selection workshops, participants have to apply techniques facilitating idea evaluation.

A design process based on this fundamental ideation process element would be composed of an enchainment of several such elements, each element leading most notably to an increased level of concretisation of the ideas [15]. Typically, there are also multiple parallel paths, each path representing a particular set of ideas being worked out further. For the particular design problem of SPP, the authors proposed the schema depicted in Fig. 2.

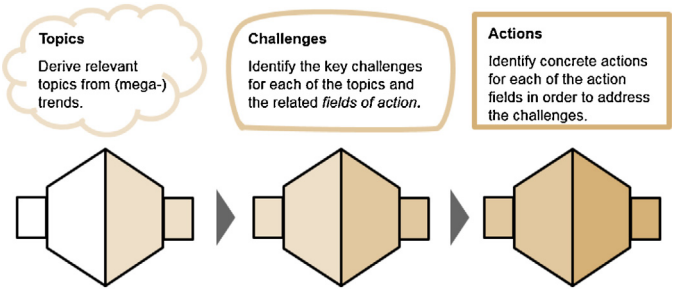

Fig. 2. SPP process based on integrated ideation process elements.

SPP seeks to find a creative yet systematic way to derive concrete actions to carry out to respond to trends that influence the organisation. These trends are manifold and related to several fields, such as technology, economy, ecology and society. The first process element deals with the identification of key topics derived from a list of (mega-)trends collected in the preparation phase, typically on the basis of relevant studies. Opening up the mind-set for the potential impacts these trends will have on the company is the key success factor for the divergence phase of this process element. Techniques like brainwriting, extreme scenarios, etc. are well suited to achieve this [16]. In the convergence phase, topics are prioritised, typically based on the company strategy, which requires the participation of top management representatives in the ideation team. The ranked topic list serves as the primary input for the subsequent process elements which deal with the particular challenges linked with each topic. Several such second-level elements might be triggered in parallel, depending on the process requirements and constraints in terms of time, resources and completeness (Fig. 3).

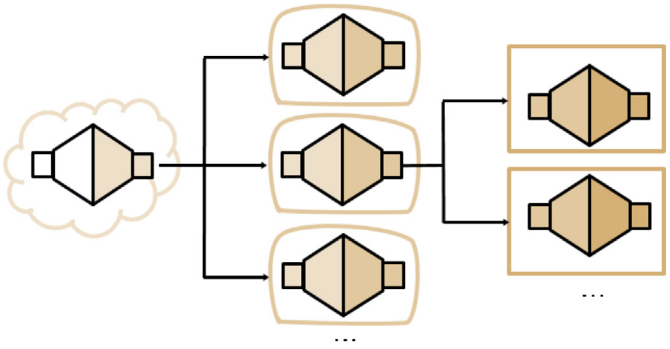

Fig. 3. Triggering process elements per topic and field of action.

For each selected topic, challenges (linked to a specific e.g. technology trend) have to be identified by the group during the subsequent divergence phase. Here, it is important to involve experts on a program management level, i.e. experts having collected experience in numerous projects. For each challenge the group identifies, fields of action addressing these challenges shall be defined in the convergence phase. In this process element, the timing of action fields shall not yet be taken into account. The focus has to be on *what* has to be done rather than on *when*. The *who* is also important to consider in both process elements, since it has strong implications on the ideation team composition of each subsequent ideation session. The objective of the final process element is to define concrete projects addressing the fields of action per challenge. The divergence phase delivers relevant project ideas which are subsequently elaborated as project sheets containing key project data (objectives, motivation, resources, timing, budget, dependencies, etc.) that will be used for updating the company's strategic long-term strategic planning instrument, typically roadmaps.

It is important to highlight that the suggested SPP process is to be seen as a *model* which need to be implemented and adapted to specific organisation's context. Each of the three process elements does not necessarily correspond to one single ideation session. There may be several ideation sessions per process element, and the phases of divergence and convergence may be ran through in different sessions. Key success factors we found are the following:

(1) Full bi-directional *traceability* of all the results over all sessions: this is essential for sustaining the stakeholders' motivation and for understanding the decision history.
(2) Consequent analysis of the *interrelationships* between results: building a network of topics rather than independent lists help understanding dependencies.
(3) Excellent *moderation and facilitation*: experts have to be guided for stepping out of their boxes in order to capitalise on their expertise and creativity potentials.
(4) *Team composition*: diversity in represented departments and personal traits in all the collaborative activities is the essential ingredient of any integrated design process.
(5) *Perfect preparation and post-processing* of each session: key preparation factors include the (strategic) selection of the ideation team members as well as the objectives and techniques to achieve those. Post-processing has to make sure that all results are properly documented, even intermediate ones if they are useful for traceability.
(6) *Regularity* of sessions: ideation sessions need to be organised in a regular rhythm over the year so as to maintain the spirit of the process and the teams.
(7) *Constructive ambience* and environment: while critical analysis of ideas can be useful at certain stages in the process, a constructive way of communicating is vital for fostering creativity and active participation.
(8) *Governance*: the process should be owned and driven by a steering team that assures its organisation-wide impact. Networking the SPP process with relevant other strategic activities in the company helps assure the management attention necessary for sustaining the process and implementing its results.

Thanks to its strictly subsequent phases of divergence, convergence, and consolidation, the proposed process model intrinsically renders the progress measurable, which is very important in industrial organisations.

5. Industrial case study

We applied the SPP process model in the context of one of the largest worldwide automotive tier-1 supplier who was looking for a systematic approach to SPP for their worldwide production network [17]. For evident confidentiality reasons, we are not allowed to present any details about the process and the results obtained during its execution in the course of our pilot project over one year. We will therefore focus on presenting the key steps and the main insights we could get from them.

One key challenge was to integrate stakeholders of production, development and procurement in this effort. A core team was established which was both part of the steering consortium and the ideation teams. The team size varied between 8 and 15, depending on the experts' availabilities and the roles and expertise required for the particular objectives of each session. Influential representatives of the three areas production, product development and procurement have been part of this core team, which was a significant change with respect to existing practices in the organisation. The production experts were in the leading position, since the whole initiative was driven by them with the key objective to introduce a sustainable systematic strategic planning process that starts from megatrends and ends up in concrete project ideas placed in the production technology roadmap. A major requirement to the result was that it should reflect the holistic, integrated view of the three involved areas on the production planning, leveraging the role of modern production technology as a driver for innovation both of products, processes, and the company's global organisations including suppliers.

Moderated ideation sessions with integrated design character have been carried out about every 5 weeks over one year in a way that the three process elements have been traversed exactly once over this time period. The duration of each session was half a day or an entire day, with the team composition remaining stable over the complete duration. Each session was prepared very carefully in terms of the selection of the detailed objectives, the topics chosen, the experts to be invited and the roles they should assume, and the methodology to be applied. Likewise, the results and experiences made in each session have been consolidated and documented in a systematic manner. During each session, tool support was deliberately kept basic in order to maximise the efficiency of human interaction. Mind maps had a key role, including the representation of links between dependent ideas. A focus was set on parallel group work, and the common discussion of all group results to take idea generation and/or selection even further. In this way, all the results have been produced entirely by the expertise and creative power of the ideation team members who were all employees of the company. The external moderator's role was only that of a facilitator of the application of integrated design approaches to ideation for planning purposes.

The point of departure was a regularly updated set of about 40 societal, economic and technological megatrends that serves as a basis of any strategy definition in the entire company. The session's key objective was to derive by voting from this vast list of trends three trend clusters having the highest relevance for the company's production technology. The result was subsumed in three artificial terms: *Glocalisation* (the target conflict between Globalisation and Localisation), *Flexagility* (being flexible and agile), and *Hybridisation* (combination of several technologies in the products). In a next step, the experts worked together in small groups in order to ideate about topics they consider particularly relevant for these selected trends, as well as for organisation and cost (constraints imposed by steering team). About 130 ideas have been generated and consolidated in about 30 topics and six mutually linked clusters (processes, employees, competences, production network, external collaborations, infrastructure). To illustrate one concrete example, the balancing of the complete (internal and external) production network was one of the topics selected for further investigation.

The following ideation methodology was applied to each of the selected topics during the next phase:

(1) Getting a common understanding of the topic.
(2) Designing a target scenario for the topic ("to-be" scenario).
(3) Describing the actual situation ("as-is" scenario).
(4) Identifying the deviations between the two scenarios (using suitable rating scales) and the causes for these deviations.
(5) Clustering the causes for the derivation of fields of action.

(6) Describing each field of action and identifying resources required to define concrete actions related to the field.

One of the about 15 action fields linked to the example topic is the improvement of the support by the organisation and the process for the flexible use of plant and equipment within the global network. For each of these action fields, the affected organisational units, as well as a rough effort classification have been determined. This was important for including experts from the affected units in the ideation sessions of the subsequent ideation process phase.

The objective of the final process element was the definition of concrete actions related to the fields of action based on the guiding thought: *what* needs to be done in order to address the respective field of action. Actions were then packaged into project sheets having the following rough outline structure: problem description, measurable objectives and indicators for success, methodology, opportunities and risks, estimated cost, key stakeholders, and timeframe. Another key information to be made explicit on these sheets is the relevant links to other projects, in particular (company-wide) strategic projects. This is essential especially for determining the importance of a particular project with respect to others, as well as its impact on a global level. About two to three projects per action field have been defined. Key data for all these project sheets have been elaborated in the teams during the ideation sessions, and elaborated in greater detail in the post-processing phase.

At the end of this process the project sheets were sufficiently detailed for being placed in the TRM. Thanks to the consistent involvement of product development and procurement representatives, the SPP roadmap could be easily networked with the development and purchase roadmaps, leading to an *integrated innovation roadmap* (IRM) which results in a holistic decision support instrument for the strategic long-term planning representing a significant progress with respect to previous instruments and practices. According to the feedback of all involved parties, the SPP process based on integrated design principles has brought the following principal added values:

(1) Regular, intensive direct internal communication and collaboration between stakeholders across the entire organisation for the elaboration of strategic topics.
(2) Visible progress thanks to the systematic approach, the careful preparation of each session and the effective moderation of the latter.
(3) High number of relevant ideas and full traceability of their evolution and dependencies of other ideas and projects.
(4) The networked structure of all topics in work is always visible and therefore facilitates the holistic view.

Although the case study was carried out as a pilot project with limited resources, the involved stakeholders' experience and result convinced top management to deploy the SPP ideation process on business unit level in a way that all three process elements are ran through in one year, based on a dynamic network of ideas that is updated after each single session. The subjects chosen are signified as TIW (topic in work) in Fig. 4.

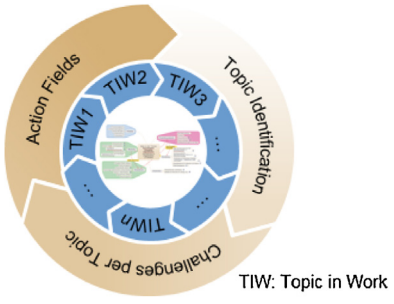

Fig. 4. Deployment of a TRM process "rolling" over one year.

6. Conclusions and outlook

We have proposed a strategic production planning process based on core principles of integrated design and compliant with key requirements imposed on strategy processes by big global industries. The fundamental process element is a sequence of guided and facilitated divergent and convergent thinking of ideation teams that are composed of company experts from different domains, most notably from production, development, and procurement. Three serial process steps are required to take ideas from megatrend-level of concrete projects. This has been validated with great success in a pilot project carried out in a business unit of one of the worldwide largest automotive suppliers. Together with this supplier, we are currently working on the definition of KPIs (key performance indicators) for both the efficiency and effectiveness of the process, which is absolutely necessary for its management and continuous improvement. These indicators will go beyond existing KPIs for process performance in that they shall measure the extent to which the process achieves the integration of stakeholders, and the consequences of this on the process output.

Our initial hypothesis that core principles of integrated design approaches applied to strategic planning activities in industrial organisations can significantly outperform existing practices, has clearly been confirmed. Although adequate performance measures are still a subject of further research, the benefits we observed are obviously significant and multi-dimensional. Thanks to its focus on systematic human interaction and diversity, the integrated design approach can take strategic technology and innovation planning to a level that has not been experienced with traditional approaches. The simple yet powerful systematic structure that we propose tackles the difficult challenge of guiding all stakeholders in the process and rendering the process manageable while still being generic enough to be deployed in various different organisations.

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