An Integrated Design Approach to Innovation Roadmaps and Strategic Production Planning

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List of Abbreviations and Symbols

AD	Advanced development
BRIC	Brazil, Russia, India, China
BU	Business unit
CPS	Creative problem solving
Ed.	Editor
Eds.	Editors
e.g.	For example (abbreviation of Latin “exempli gratia”)
FLM	factory lifecycle management
GP	Group production
KPI	Key performance indicator
Iss.	Issue
IRP	Innovation roadmapping process
No.	Number
NPD	New product development
OPM	Open problem solving model
P	Production
PD	Product development
PLM	Product lifecycle management
PSP	Planification stratégique de la production
R&D	Research & development
SCM	supply chain management
SPP	Strategic production planning
SWOT	Strengths, weaknesses, opportunities and threats
TRM	Technology roadmapping
Vol.	Volume
WLC	Workload control
WoS	Web of Science

WS	Workshop
ZF	ZF Friedrichshafen AG (company name)

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1 Introduction

1.1 Initial situation and context

Manufacturing companies are in the “Fourth industrial revolution”, which is strongly linked to the internet of things, cyber physical systems or, as it is referred to in Germany, Industry 4.0. This means that companies are confronted with many uncertainties. But the one thing that is certain is that everything is changing very quickly and companies must constantly validate their technologies regarding their maturity for use in an “intelligent” environment [GEN2016]. This implies rapid technological development along with new technologies, such as lightweight material processing and additive manufacturing on the one hand. And on the other hand, a huge amount of data must be managed with knowledge-based manufacturing systems, integrated information technology systems and agile process design [GEN2016]. Furthermore, companies must learn about and decide how rapidly emerging megatrends impact them. In this environment of uncertainty and rapid change, production is even more impacted by OEMs, product engineering, procurement and costs.

All these factors spur the growth of strategic production planning as companies are forced to find solutions for the question of how to be prepared to meet new challenges/technologies and react quickly.

In this thesis, the long-term strategic planning of production technologies in the best possible coordination with product and system technologies shall be denoted as “strategic production planning” (SPP). The key objective is to establish a holistic integrated view of requirements and solutions to innovation challenges in product manufacturing for the future and to enable the organization to prepare for those in a timely manner.

In addition to technological issues, industrial changes coming from Industry 4.0 create societal concerns in areas such as the acceptance of human-robot collaboration, worker safety and the environment.

1.2 Research problem

To face the challenges outlined in section 1.1, production should operate in an integrated fashion with interdependent areas, in particular product development. However, in the coordinated evolution of products, processes and production systems, production is typically seen simply as the producer following product development [TOL2010]. As such, production is not expected or even allowed to consider anything other than what design gives it to produce. As depicted in Figure 1-1, based on Dekkers [DEK2005], production is often downstream from product design and engineering and has only one channel to management: giving feedback on the continuous improvement of the product. There are no communication channels from production to engineering, design or research. Even in researching the interface of production and product design and engineering, the subject matter is either too short-term or close to the shop floor, or the focus is on the product rather than on the production (e.g., [DEK2013]).

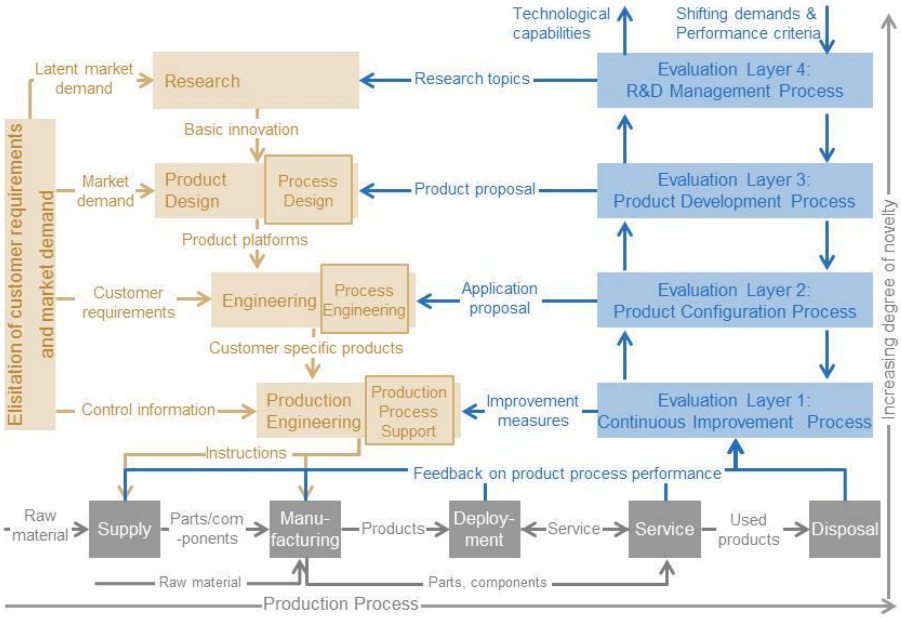

Figure 1-1: Generic engineering process reference model [DEK2013]

In addition, practical experience shows that in product development departments there is often a lack of understanding as to why production wants to move beyond being "only" the producer. Very often stakeholders are aware of the usefulness of strategic production and sometimes even resist cooperating because they think their effort is wasted [LEE2012]. In their opinion, production is strategic enough if it produces innovative new products well. This opinion is intensified by the fact that product designers and production planners are often physically separate from each other [UNZ2015]. Nevertheless, the

planning process should not be seen solely in terms of being product driven. Production must keep abreast of advances in technology and plan accordingly [FLA2014].

It is difficult to approach production through the wider lens of "innovation". Nevertheless, it is necessary to construct new competencies to bridge foreseeable technology gaps [GOK2007] and to identify new core capabilities and competences to focus on [BAR1995]. Production must be innovative in all fields it is part of. That means the organization of the production department, the processes used (not the technology), the culture, the labor force, the tools, methods, etc. should be appropriate and therefore innovative. In addition, the challenge is to extend the scope from pure technology planning to integrated strategic planning of technologies and their associated competencies, infrastructure, support processes and deployment in the organization as well as the products and services delivered [HAK2006, FLA2014]. This will lead to innovation planning beyond pure technology planning.

To survive in this unsteady environment of ever-changing product requirements and fast technological progress, production seeks to expand know-how and infrastructure. Nevertheless, it struggles to develop the range of capabilities needed and its ability to respond to changing market and business conditions [FER2011]. In addition, production should be supported by a holistic process that guides it through the given complex environment. Furthermore, production searches for tools and methods to help it plan systematically, reliably and holistically.

In summary, this thesis seeks to address the following three problems industrial production is confronted with:

- Production follows product development, although it should be integrated with product development. Product development departments consider corporate innovation their domains and production as a necessity rather than as another opportunity to innovate.
- Innovation in production is not seen in a wide context, because production operates in its own areas. Production mostly engages in improving technical planning for product lines on the shop floor; however, integrated long-term planning with its associated competencies, infrastructure and support processes is lacking.
- Holistic approaches that guide production through the uncertain environment from trends to projects are not available.

1.3 Motivation and scope

The motivation driving this work is to establish an integrated approach to SPP addressing the problems mentioned above in a way that fits in an industrial context and thus meets the practical requirements of industry.

In particular, the following key research questions are addressed:

1. What is the best way to guide production from relevant megatrends to concrete projects in a systematic, holistic and traceable way [FLA2014]?
2. What is the most systematic approach to open strategic production that facilitates consideration of topics with a wide-angle lens to not only focus on technology but also take into account the processes and organization, among others?
3. How is it possible to ensure that SPP is integrated, structured and alive?
4. How can the approach be successfully implemented in a corporate context?

These questions will be addressed in the context of uncertainty in strategic production planning n this thesis, which focuses on the process from the detection of megatrend requirements through idea generation up to concrete projects addressing the identified requirements. The horizon for planning and foresight for innovation driven by manufacturing is about 20 or more years.

In terms of tools supporting this process, we have chosen technology roadmapping (TRM), because of its importance in industry as a well-established strategic management tool for organizations to adapt themselves better to modern marketplaces [PHA2004, FLA2015b]. TRM is suitable when diverse communities of practice, including production, product development and procurement, negotiate and exchange knowledge. It also has a great potential for face-to-face interaction and/or ambiguous lines of authority [SAP2004]. The techniques in fast-start roadmapping workshops enable key stakeholders to address strategic issues efficiently using the visual structure of roadmaps to capture, discuss, prioritize, explore and communicate issues [PHA2013]. Moreover, the choice of TRM as strategic planning tool was strongly inspired by the industrial context in which this thesis was carried out.

This focus allows a well-founded differentiation with respect to closely related fields that are not examined in this research work, such as innovation management, idea management and trend management, manufacturing control and execution systems, software tools, other strategic production planning tools and the content of technology trends. Thus, the main interest lies on the creation of a strategic production planning process. The methodological approach is a complementary mixture of scientific literature and practical qualitative research, mainly in the form of feedback from practical implementation of the process as a case study at ZF Friedrichshafen AG.

1.4 Thesis structure

This thesis consists of four main parts, as depicted in Figure 1-2.

Part I specifies the thematic classification of the thesis in the research landscape in terms of the state of the art in SPP and TRM. First, a literature review of the broad, open research area of SPP was made. Then TRM in the classical sense and in particular in the context of SPP was investigated. Both reviews are supported by the open source bibliometric tool CiteSpace. Part I concludes with process requirements for SPP derived from the literature review that will be considered in process development.

Part II starts with the specification of the research question, the objectives, as well as the research methodology based on the key questions raised in Part I and the literature review investigations. Our key idea is to adopt methods from design research to address the research challenges. Hence, Part II presents the results on a more specific literature review in this area with respect to focusing employees' creative efforts on strategic planning. Based on this and derived process requirements, a generic process for integrated strategic production planning is proposed as the central contribution of this thesis. We call it "Innovation and Roadmapping Process for Strategic Production Planning" (IRP SPP). The latter's three main process steps are described in detail along with the success factors identified for their deployment. In addition, a measurement approach is proposed for IRP SPP.

Part III details the case study in terms of application of the process in a company context, the German automotive tier-1 supplier ZF Friedrichshafen AG, denoted "ZF" in this thesis. Furthermore, the measurement approach is tested for the pilot phase in the case study.

Part IV concludes with a summary, an analysis of the thesis' limitations, as well as several perspectives for future research activities.

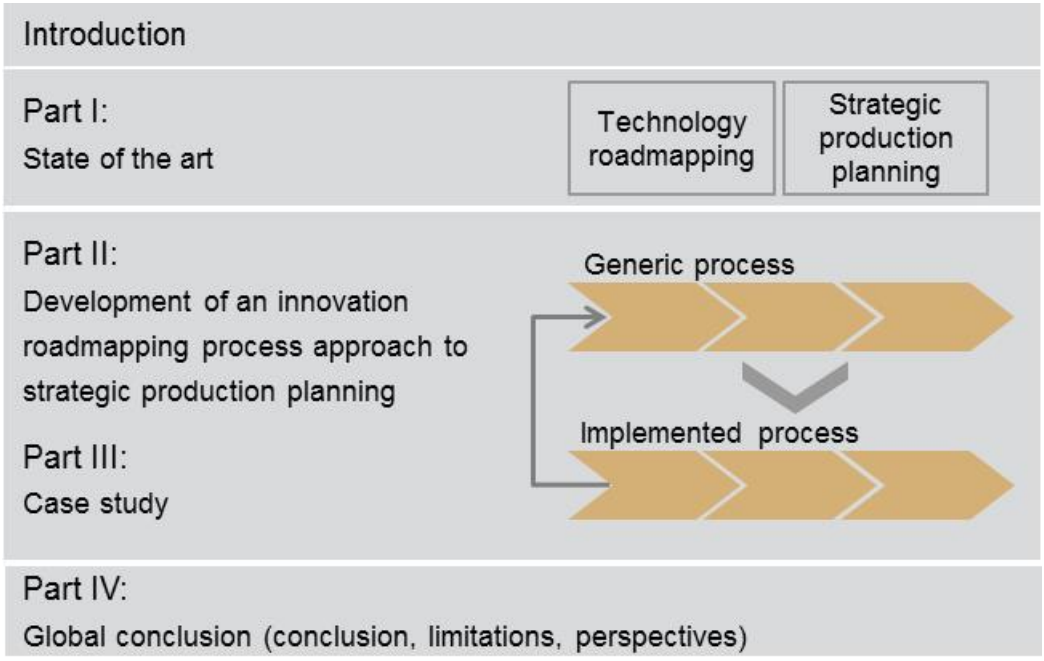

Figure 1-2: Structure of the thesis

Part I:

State of the Art

2 Literature review methodology

The two research fields of SPP and TRM are investigated in this literature review.

The literature review of SPP intentionally excludes the subject of the technical planning of production lines, which is commonly referred to as "production planning" in professional and research literature. The subject here is rather the long-term strategic planning of how to innovate in manufacturing in a corporate context through timely investment in future technology, competences and processes. In light of Industry 4.0, decision-makers have to decide in which technologies and transformation activities to invest, and what would aid their decision-making process.

To ensure a sufficiently wide range of sources would be drawn from in a systematic manner, this literature research was complemented by a bibliometric analysis using CiteSpace and Thomson Reuter's Web of Science (WoS). The WoS is searchable with complete bibliographic data [CLE2011], ensures a good coverage of important journals in the economic research field worldwide [CLE2008] with data sources that date to the beginning of the 20th century [FAL2008] and tends to have a low number of incorrectly captured data [CLE2011]. CiteSpace II from Chen [CHE2006] was used as a bibliometric analysis tool mainly because of its powerful analysis capabilities and its compatibility with WoS data. This software creates networks that model patterns in research relations in the form of graphs with nodes and edges.

In order to access the right source data, we manually filtered search results that were not relevant to our field of investigation.

In this context, co-citation analysis and a citation-based bibliographic coupling were chosen. Both types of analysis assume that references indicate the subject of the corresponding article and clusters of articles using similar references or common referenced articles imply a topical closeness. Because an article should be published within a certain time, cited articles are called "intellectual bases". Articles based on similar sources in clusters like in co-citation-based bibliographic coupling constitute research fronts [PER1994]. Both types are pictured in Figure 2-1, which was inspired by Boyack et al., Gipp et al. and Havemann [BOY2010, GIP2009, HAV2009].

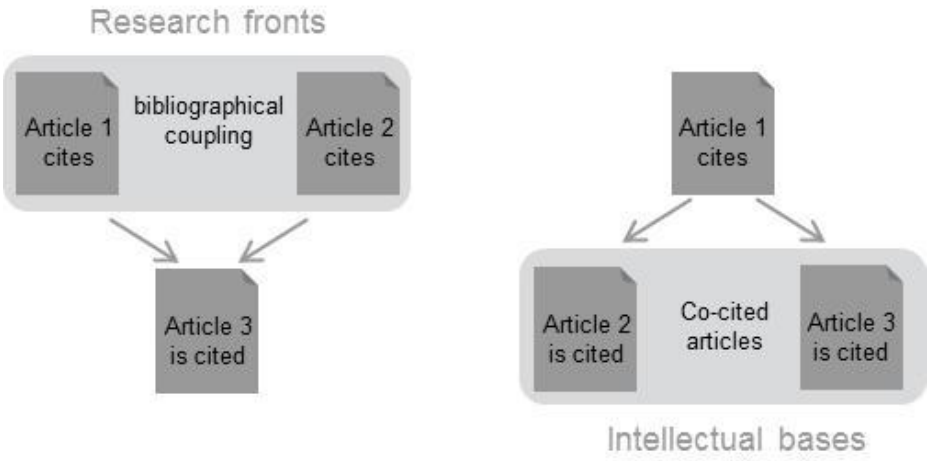

Figure 2-1: Research fronts and intellectual bases

In the network of research fronts each node represents one research article and is linked to other bibliographically coupled articles. This means that there is an overlap in the list of references of the coupled articles. The more references articles share, the stronger these articles are coupled [FAL2008]. Each node's size indicates the number of times the corresponding article has been cited, according to WoS. In the network of intellectual bases, nodes represent co-cited articles where the size of nodes represents the citation frequency.

Although further types of analysis exist, those explained above are the most important because of their wide distribution [BOY2010, PER1994].

CiteSpace analyses are based on the title, authors, abstract, keywords and references of each publication in the WoS database. The fact that this excludes papers that contain the query terms only in the body did not represent a serious restriction, as we can expect that papers dealing with SPP as a methodology would certainly mention related keywords elsewhere than the body.

The bibliometric analysis was complemented by a "classical" literature review in order to be sure not to miss literature that is not part of the WoS, in particular articles published in non "A"-rated journals and many German papers. Furthermore, potential defects of bibliometric networks had to be prevented. Consequently, content-related proximity through bibliographical coupling is not always guaranteed. Articles in a network can be contracted from one or more review articles in a figurative sense. Also, citations may reflect personal relationships rather than similarity in subject matter.

3 Strategic production planning (SPP)

3.1 Methodology and scope

Approaches to SPP for manufacturing innovation planning is a quite specific research subject. A simple search with the query “strategic AND (production OR manufacturing) AND planning” resulted in no relevant papers. Even with the keyword “strategic”, either very short-term solutions for the shop floor or articles not specific to production were found (as already indicated in Chapter 1.1). However, parts of solutions exist in literature that needed to be revealed in the following review. Orientation showed dependencies, related and neighboring areas of SPP that seemed to influence the strategic production environment. Figure 3-1 illustrates confirmed dependencies in the production environment in a basic form.

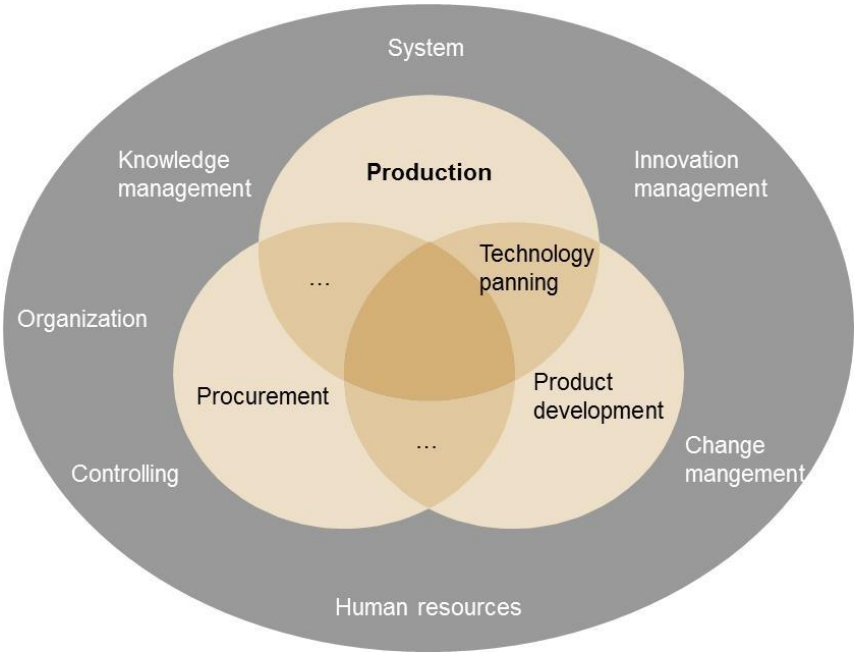

Figure 3-1: Production environment with dependencies

Several CiteSpace networks of research fronts and intellectual bases were made. In addition, the database for the networks was built with keywords based on confirmed dependencies in Figure 3-1. The keywords "production"/ "manufacturing" were combined in AND operations with the keywords "planning", "technology AND organization", "innovation AND plan", "human resources AND system" and "organization AND innovation".

The generated networks were analyzed for concrete relevant topic networks and clusters. Unfortunately, no interesting network of articles in given context was found. Therefore, the networks are not shown in this work. Most articles were about subjects that were too related to the shop floor and had a short-term focus. Those articles along with relevant key messages are listed in Chapter 3.2.

In particular, we investigated more precisely the community of The International Academy for Production Engineering (CIRP), as this is the world's leading organization in production engineering research and is at the forefront of design, optimization, control and management of processes, machines and systems. The Academy has a restricted membership based on demonstrated excellence in research and has some 600 academic and industrial members from 50 industrialized countries [CIR2017]. Networks were made in combining the query "CIRP AND production" with the network "technology planning" and "planning". In addition, a classical literature review was made in the areas that CiteSpace analysis revealed as interesting.

Chapter 3.2 summarizes interesting approaches coming from the CiteSpace network analyses and classical literature review. In addition, Chapter 3.3 illustrates the environment of production in facing challenges in terms of Industry 4.0.

3.2 Approaches to SPP

Production research investigates typical areas such as technology/production planning, optimization, monitoring, reconfiguration, quality, costs, simulation and control. This indicates that SPP involves much research in its typical environment/scope of action where new technology or production processes are investigated to achieve better productivity. In fact, production innovation is seen as an avenue to firms becoming more efficient or effective, as already mentioned as a research problem in Chapter 1.2.

From the search networks production AND innovation AND organization, as well as production AND "technology planning," one article emerged as important to this thesis. Cohen et al. [COH1990] conducts research in the field of knowledge management in R&D, where he offers a model of firm investment in research and development (R&D) in which R&D contributes to innovative performance by detecting important knowledge, named "absorptive capacity" of

a firm. The aim of absorptive capacity is to not spoil future development of a technical capability because of a lack of investment in an area of expertise.

The network search "(production OR manufacturing) AND technology AND organization" revealed several interesting aspects. Organizational change in process reengineering can only take place through the combination of information technology, as a key change enabler, the understanding of current practices, organizational and human resource enablers and a total quality management-based philosophy [LOV1997]. Schoensleben [SCH2009] as well focuses on changeability but in strategic production concepts. However, the word "strategic" in this context means the network of production locations in terms of facility layouts or planning and control systems. Mazzola et al. [MAZ2009] reveals networking as the most important competitive strength to gaining efficiency, collecting knowledge and pursuing globalization. But no details are given as to how to build or maintain a network, specifically no approach is given as to what specific networks are needed for SPP in our context. Vancza et al. [VAN2011] mentions that production engineering should integrate a rich body of interdisciplinary results together with contemporary information and communication technologies to achieve cooperative and responsive manufacturing. Challenges facing cooperative, responsive manufacturing enterprises are inter alia assigned to organization, network design, governance and communication, decision-making, management, and execution (control, monitoring, performance evaluation and feedback, information gathering and transparency of information).

Tolio et al. [TOL2010] highlights the coevolution of manufacturing, product and processes. In the context of formulating a new coevolution paradigm, the integrated view of products, processes and production systems during their evolution and changes over time is of great importance. Approaches need to be framed that support coevolution becoming suitable to addressing and solving companies' specific problems in different contexts. In addition, the current state of the art needs to be classified related to coevolution of products, processes and production systems. Hereby, future research priorities will be identified by highlighting promising research topics.

3.3 Environment of SPP

So far, production and product development were shown in a linear way. Production is downstream of product development, as illustrated in Figure 3.2, which was inspired by different approaches from Schuh et al., Westkämper, Wheelen et al., Dürrschmidt and Riffelmacher [SCH2014, WES2002, WHE2012, DUE2001, RIF2002].

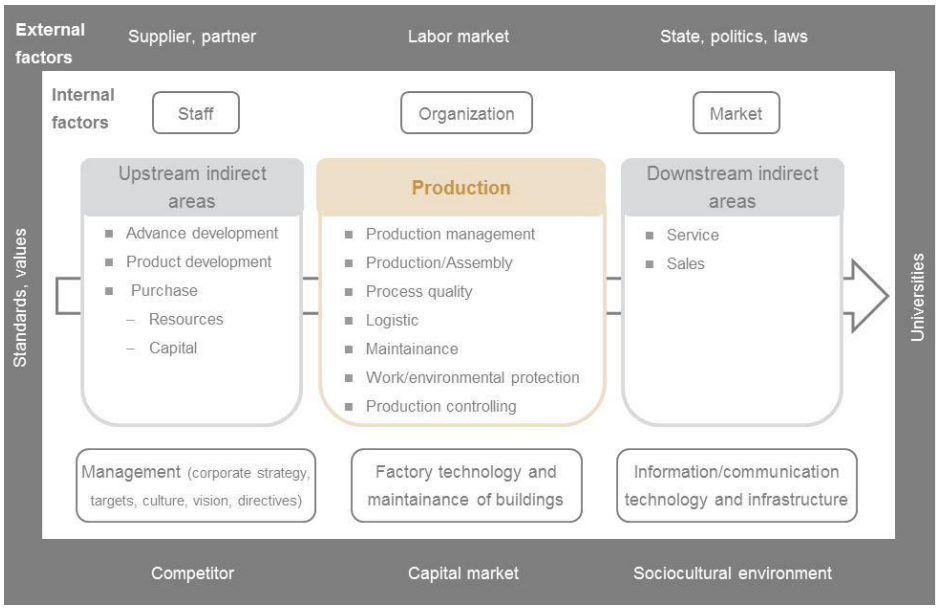

Figure 3-2: Internal and external influencing factors on production

But as mentioned in Chapter 1.1 production is in the complex ever-changing environment of Industry 4.0 (e.g., additive manufacturing). Therefore, production is forced to act in an integrated fashion with product development and procurement in cooperation with upstream and downstream input [TOL2010]. Unzeitig et al. [UNZ2015] reveals the importance of production cooperating with product development during the entire product development process. As a result, production planning departments benefit from a continuous flow of information during different stages of the product design phase, which means they are able to cope with uncertainty in product planning at the earliest possible stage and successfully manufacture complex products . But knowledge sharing between all stakeholders is hampered if product designers and production planners work in different enterprises, which is the usual case in today's supply-chain based economy.

Because classical downstream areas merge with production, flexible and adaptable systems are needed. Tolio et al. [TOL2010] illustrates dynamic manufacturing in collaboration with product development. External driving forces and the company strategy are central influencing points. Silchera et al. [SIL2013] offers a holistic management model where production stands in the middle. Side aspects are highlighted for the life cycle phases, such as product lifecycle management (PLM), supply chain management (SCM) and factory lifecycle management (FLM). This shows the dependencies of production between design and development, as well as supplier network design.

Dohrman's [DOH2007] complete enterprise-wide PLM system shows an integrated approach with stakeholder perspective. Figure 3-3 depicts the areas of production, design and procurement/purchasing. Since all areas should consider input from the others, bidirectional arrows are used to illustrate this. It is not sufficient that production only considers input from other departments; it must also give input. The PLM system in the middle of the picture interconnects the entities in terms of information flow. This bidirectional information flow represents holistic production planning.

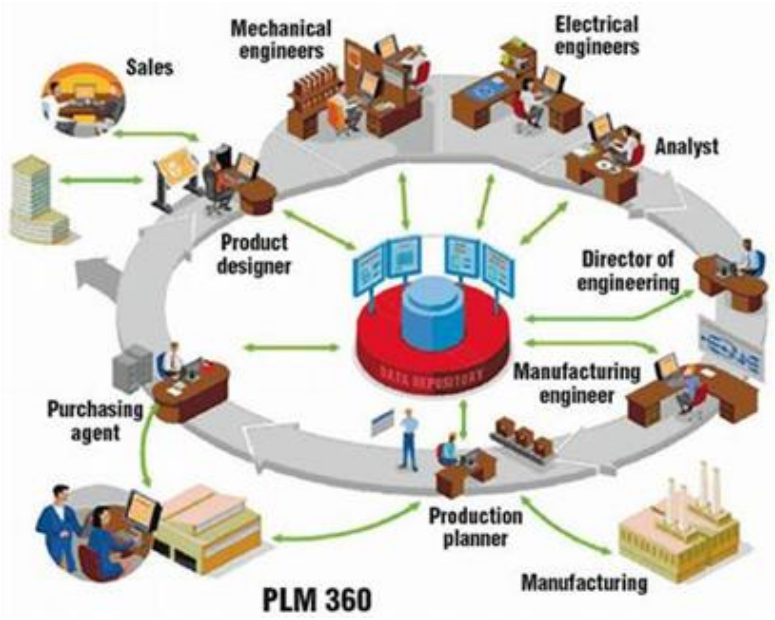

Figure 3-3: Dohrman's complete enterprise-wide PLM [DOH2007]

4 Technology roadmapping (TRM)

4.1 Methodology and scope

As TRM is the chosen tool in this thesis, a literature review of general TRM was made. In order to facilitate and guide our literature review on TRM, a CiteSpace network for the keywords “technology AND roadmap” was built, illustrated in Figure 4-2. We first focused on those articles with structurally outstanding properties in the network, in particular, those having highly networked notes and/or high citation counts. Departing from these, we studied their reference bases with a preference for those references that have structurally interesting properties in the network and whose topics are in relevant domains. To ensure the bibliometric analysis would be as complete as possible, it was supplemented by a classical literature review [FLA2015a].

To show detailed treatment of TRM in production, in Chapter 4.3 we will delve into the production context and specify the findings of TRM in production with bibliometric analysis. Several CiteSpace networks were created to analyze the state of the art of technology roadmapping in production. Since the queries “production technology roadmap”, production AND “technology roadmap” did not deliver any relevant results, a network was built for the query roadmap AND production, depicted in Figure 4-4.

Chapter 4.2 will give insight into the findings of the research analysis of TRM, whereas Chapter 0 will go into the research analysis of TRM in SPP.

4.2 TRM aspects

Roadmaps come in varying configurations with varying purposes such as forecasting, planning and administration [LEE2005, GER2013]. The most typical roadmap consists of layers such as market, product and technology that cover a horizontal timeline. In these layers, the evolution of the competition, markets, products, technologies as well as the relationships between these factors are depicted [EIR1997]. The most common approach for a TRM is illustrated in a schematic technology roadmap in Figure 4-1, showing how

technology can be aligned to product and service developments, business strategy and market opportunities.

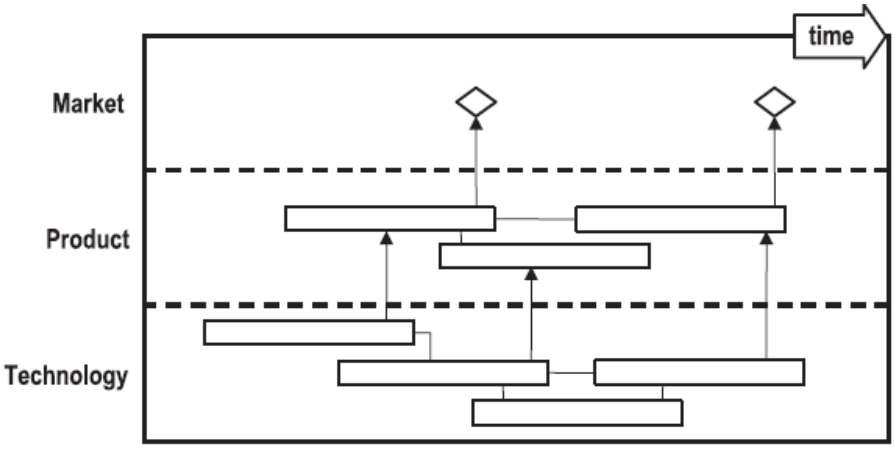

Figure 4-1: Schematic technology roadmapping [EIR1997]

The formalized roadmap process is composed of the three phases: preliminary activity, development and follow-up activity [GAR1997]. The architecture of a roadmap consists of a planning horizon and key milestones [PHA2003a]. Motorola was the first to publish about the use of a technology roadmap from the viewpoint of a practitioner [WIL1987]. As a further example of its use in industry, Philips Electronics confirmed the technology roadmap as a tool for better integration of business and technology strategy [GRO2007].

TRM is an effective tool for technology planning and coordination that fits within a broader set of planning activities [GAR1997]. Over the last few years, roadmapping has been gaining momentum as a strategic management tool for organizations to better adapt themselves to modern marketplaces [GER2013].

The network of technology AND roadmap, depicted in Figure 4-2, shows three clusters of articles authored by Lee, Kostoff and Phaal. We identified that their works are fundamental for the TRM research domain in terms of the amount of frequently cited articles they authored, as well as their connectivity with other publications. The main articles of the three clusters have in common the following:

- A very extensive literature review as it presents the overview of the origins, definition, purposes, uses, objectives and benefits of technology roadmapping related to many fields of technology management, knowledge management, etc.
- Great practical experience in their suggested methods and processes.

- The subjects of discussion are solutions for current problems when using roadmaps.

Since Lee et al. [LEE2005] found that TRM is not fully exploited because of the difficulty in customizing roadmaps to fit specific needs and/or to accommodate unusual circumstances, they provide guidance for customizing roadmaps. By using a web-based system to facilitate roadmapping activities in forecasting, planning and administration, he promises to ensure the creation, dissemination and upkeep of roadmaps [LEE2005]. Phaal et al. [PHA2004] provides for the identified key gap of a robust process for technology roadmapping a fast-start method for technology roadmapping. The most cited article by Kostoff and Schaller criticizes the seemingly fragmented roadmap and presents fundamental principles for constructing high-quality roadmaps [KOS2001].

In the following pages, we will cite those authors and articles which provide significantly relevant contributions to the subject under our investigation.

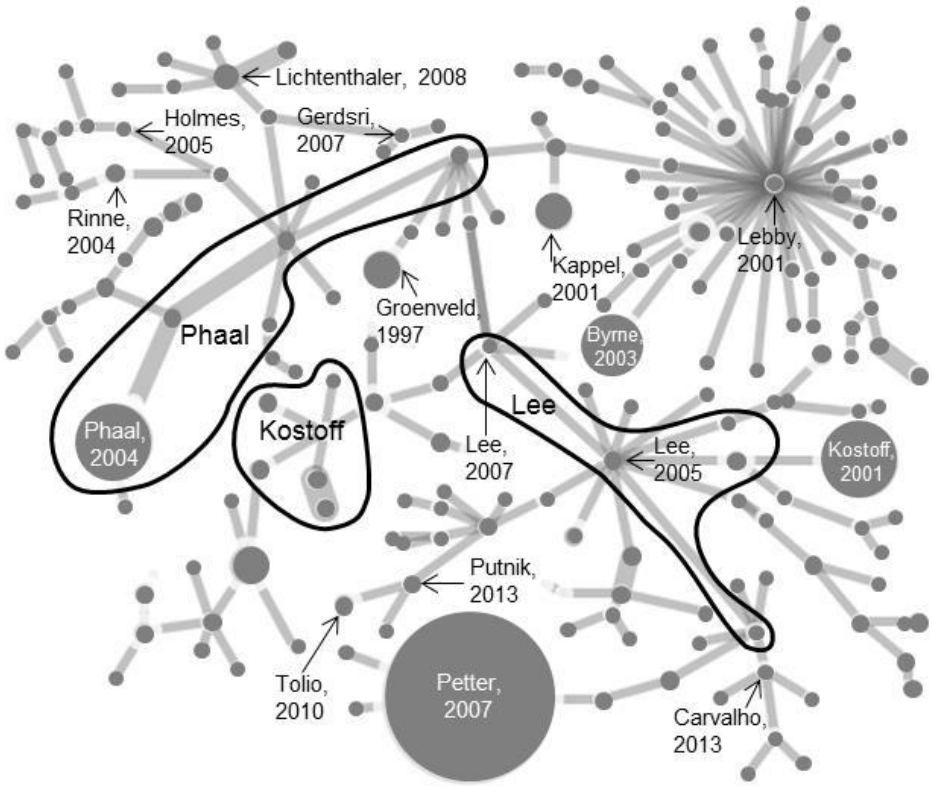

Figure 4-2: CiteSpace network technology AND roadmap

A systematic literature review published by Carvalho et al. [CAR2013] shows that the principal academic journals that discuss TRM are in "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 [CAR2013]. Furthermore, it is possible to anticipate, identify and confirm changes in industry and technology to spot market, technology and research gaps [MCM2003, PHA2003b, GAR1997]. The incorporation of knowledge of patterns of technological evolution into technology roadmaps makes it possible to detect innovation opportunities and possible market limitations [RIN2004]. A crucial condition hereby is an adequate technology assessment when creating the roadmap [HER2009a].

A major objective of TRM is to document support for technology and R&D investment decisions. Often it is not clear which alternative to pursue, how quickly a new technology will be adopted in the market, or when there is a need to coordinate the development of multiple technologies [GAR1997]. 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 [GAR1997]. Linking R&D investment strategies to business leads to strategic technology alignment roadmapping [GIN2008]. Ioannou et al. [IOA2009] insists that for TRM to be successful, the strategic decision-making process must be a collaborative one. Thus, roadmapping must take a mediating and networking approach [MIL2007]. This can happen by the integration of suppliers in the TRM process [GOE2008], a cross-functional approach to product and technology planning and vision building, as well as the ongoing coordination between corporate laboratories and business units [KAP2001]. Because many people are affected, there are synergies to be gained by involving team members from different departments [GER2007].

In considering the roadmap as a networking approach, team members from both technical and commercial functions, such as R&D, product development, manufacturing, marketing, finance and human resources [ALB2003, PHA2003b], are to be involved in consensus building, which connects an expected future (descriptive) with a desired future (normative) [ZWE2009]. This can be achieved by using the master business roadmap to guide the creation of a technology introduction plan on the strategic level, which is further refined at the tactical level and culminates in project plans for implementation [HAK2006]. In addition, business and development areas approximate and work very closely, not only in the roadmapping process, but also during the development phase [OZA2015].

Adequate attention from management is necessary to motivate the roadmap team to consider several options, address management's key concerns and justify its positions with a clear rationale [KAP2001]. Involvement will increase because it is known that the output would be used in funding decisions because participants, including decision-makers, were involved in the roadmapping

effort. Thereby, the roadmap permits the investigators to then gather evidence about key decisions and their consistency. This is especially important for supporting decisions to improve the coordination of activities and resources in increasingly complex and uncertain environments [KOS2001]. Technology roadmapping must therefore deal with challenges of knowledge and collaboration [IOA2009]. To make sure that both operational and strategic technology decision-making succeed, it is important to provide a framework to place information gleaned from explicit data and tacit knowledge [PET2005]. Ozaki et al. [OZA2015] reveals that continuous information gathering is not a specific and delimited phase in the roadmapping process; instead, there should be established routines for continuously scanning the environment, collecting information and making it available to people involved in the roadmapping process.

As a decision-support instrument, risk-aware roadmapping is also a means of risk identification, quantification and mitigation. 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 along with the necessary mitigation steps and procedures [ILE2014].

One particularly important aspect of technology planning is the sourcing of new technologies to develop new competencies to bridge foreseeable technology gaps. Hereby, it is necessary to align technology and competencies within an overall roadmap [GOK2007], which is an opportunity for a company to identify new core capabilities and competences to focus on [BAR1995]. 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 toward future knowledge [AHL2013], building structural relationships among science, technology and applications [KOS2001].

In supporting the strategic evaluation of different opportunities or threats, gaps can be identified on the business level by comparing the vision for the future with the current position, and strategic options can be explored to bridge the gaps [PHA2004]. An integrated TRM methodology enables management to define its technology requirements, assess proposed technology projects against those requirements and create a balanced technology project portfolio. The improved clarity and transparency of decisions makes it easier to justify the assignment of resources to technology assessment [GIN2006].

Roadmapping acts as a logical path creator from strategy to implementation, covering strategic, tactical, and operational levels [HAK2006]. Thereby, it simultaneously captures explicit data and tacit knowledge [PET2005]. Thus, roadmapping offers a process to support holistic technology management. There are early activities like technology foresight and strategy development as well

as management of individual projects until they fully impact the company's profitability [LIS2008].

While the roadmap is fairly simple in structure and concept, its content is the result of complex processes that involve many levels of complex details [PHA2001]. 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 [VAT2012].

Another challenge is the difficulty in keeping the roadmapping process "alive" on an ongoing basis [VAT2012, LEE2007]. Lee et al. [LEE2012] argues that keeping the roadmapping process alive in the context of a communication tool means that the utilization of the roadmap increases. This can only be achieved if the roadmap's credibility grows as well. Roadmap credibility depends on the team that develops the roadmap, the roadmap users and the communication channels that are used. They also point out that an increasing willingness to cooperate, in addition to reducing uncertainty, improves the credibility of roadmap. Through extended interaction of the roadmap team with roadmap users, credibility increases as well. The key message is that the TRM team has to work together in a unified manner and engage in frequent interactions throughout all steps of developing the roadmap for it to be perceived as credible. In this way, the roadmap utilization increases and becomes a working basis for strategic considerations and decisions. Figure 4-3, inspired by [LEE2012], illustrates roadmapping in relation to classical communications theory. In terms of strategy and innovation Moehrle et al. [MOE2013] discusses roadmapping as an "extraction from the mind", i.e. the physical documentation of technology roadmapping combined with a communicative purpose.

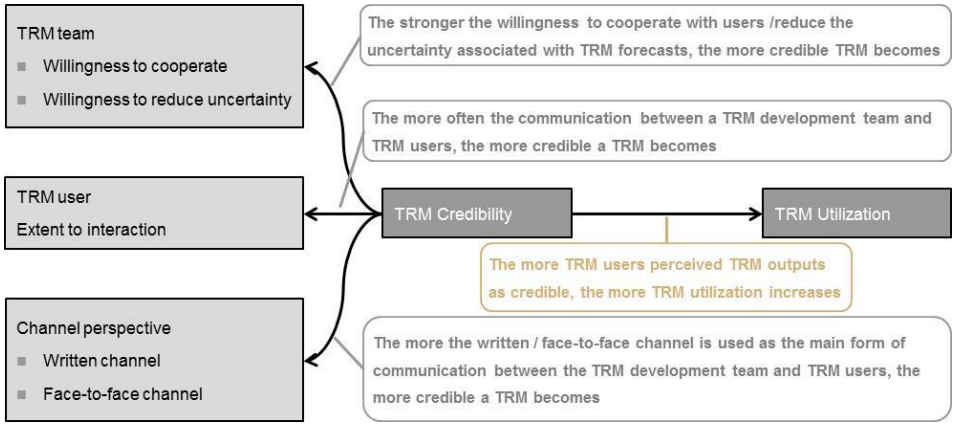

Figure 4-3: TRM based on classical communications theory

Systems are needed for determining 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 [EIR1997]. There are few practical guidelines for all roadmapping steps, in particular, for the regular updating of an established roadmap [GAR1997, PHA2004, FAR2001, LEE2007]. 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 much effort [GOE2008]. Ozaki et al. [OZA2015] found that as agile roadmapping is, it is not an isolated project but an institutionalized cycle systematically repeated. Therefore, to institutionalize a roadmapping cycle, companies need to ensure that roadmapping is not a single project that dies when it has finished.

There are many surveys investigating which stakeholders to involve in roadmapping and how [VAT2012, KAP2001]. They point out that stakeholders are often not fully aware of the usefulness of the roadmap and sometimes even resist following them because of the negative consequences for the use and continuous maintenance of the technology roadmap [LEE2012].

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 organizations [NAK2006]. So far, the evolution of roadmapping as a strategic decision-support tool has been led by management practice rather than by management theory [PHA2005, HOL2005].

4.3 TRM application for SPP

In the network "roadmap AND production", illustrated in Figure 4-4, the nine most-cited articles are marked as well as two other papers that turned out to be particular interesting. In total 20 articles were found in the specified time span from 1994 to 2014.

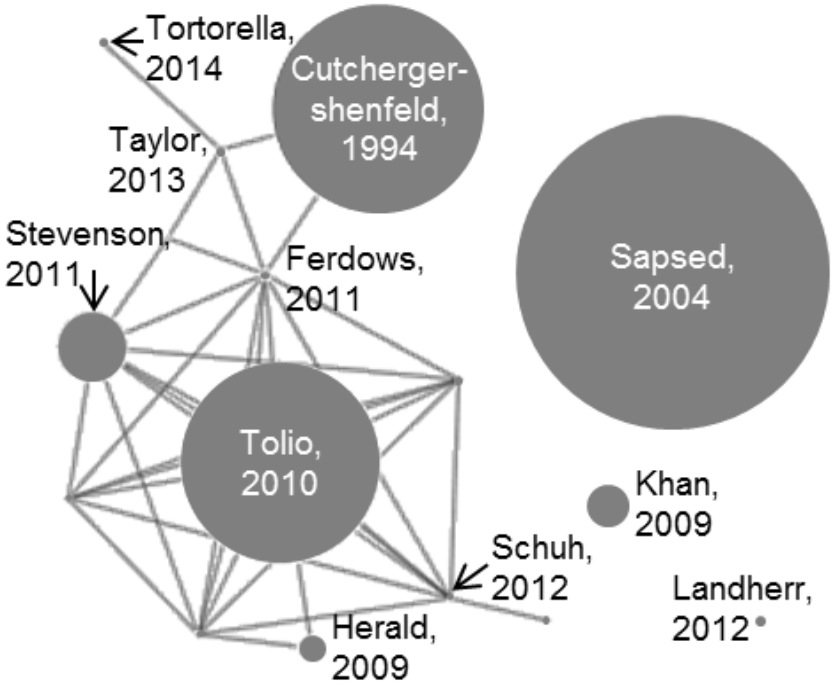

Figure 4-4: CiteSpace network "roadmap AND production"

From the CIRP keynote papers, Tolio et al. make an important contribution by investigating the coevolution of products, processes and production systems in order to address challenges like new regulations, new materials, technologies, services and communications, the pressure on costs and sustainability [TOL2010]. The coevolution becomes more and more important to be able to follow the trends towards just-in-time production and product individualization, to manufacture complex architectures, and to use new materials that require very specific production technologies. In this article, the roadmap represents the possibility of an organization to live the coevolution successfully if assimilating and deploying the research findings. However, the paper does not deal with a methodological support for companies to be able to plan and prepare their production sites for the new technologies associated with the trends that the

paper identifies. 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 [PUT2013]. Byrne et al. present a roadmap of advancing cutting-edge technology [BYR2003]. Both these papers do not deal with a systematic technology planning approach.

The most cited article by Sapsed et al. [SAP2004] describes the limitations of project management tools as boundary objects within teamwork. One analyzed program management device was the modular roadmap which is used when differentiated communities of practice, including production, services, sales, IT and company registry engage in negotiation and knowledge exchange. The roadmap was therefore analyzed for its potential in relation to the opportunity for face-to-face interaction, and/or ambiguous lines of authority. The node corresponding to this paper is not linked to any other node, indicating that Sapsed uses a scientific basis, which is completely different from the other papers. The second most-cited article by Cutcher-Gershenfeld et al. [CUT1994] deals with lean management team-based work systems. The roadmap illustrates the diverse mix of Japanese work practices and identifies important lessons for any organization moving toward greater use of team-based work systems. Taylor et al. [TAY2013] provides a literature-based taxonomy defining the core dimensions of lean that gives managers a roadmap for lean implementation. Tortorella [TOR2014] also discusses the implementation of lean production systems associated with the adoption of lean roadmaps. None of the named authors uses TRM as an approach to SPP or explains how to implement TRM successfully in an industrial organization. All of them rather use TRM as a tool for very specific purposes. The most networked article by Ferdows et al. [FER2011] outlines the necessity of factories to improve their ability to respond to changing market and business conditions and provides a roadmap for improving core capabilities in a factory. This is a first contribution to the roadmap being seen as an enabling process to making a factory fit for the future regarding its core capabilities. They discussed various aspects and used references to cover a wide range of today's production needs, which may justify the many connections the article has to other articles.

Isolated from the reference base of this network are the articles by Landherr et al. [LAN2012] and Kahn et al. [KAH2009] that, respectively, deal with aspects of intelligent management of manufacturing knowledge and the interface between product design and supply chain via a design-centric business. In both articles the roadmap is mentioned as a tool to support transformation activities. Within the other well-connected articles, central issues of production appear, such as workload control (WLC), where Stevenson et al. [STE2011] mentions the need for future research in a more detailed roadmap for successful WLC implementation in practice and operational effectiveness of systems through the acquisition and operational stages of its life cycle [HER2009b]. Related to the

increasing complexity of strategic planning Schuh et al. [SCH2012]—very connected with this issue—argues that the stronger, earlier and quicker integration of planners in product, technology and production is required. The roadmap is seen as the harmonizing of developed solution spaces from planners of each area that react to the clear visions of the future for their areas. In a collaborative decision-making process agreed-upon projects must be implemented in a technology roadmap, so that strategy and roadmap are linked in a coordinated process. In [SCH2012], the authors provide approaches to an open technology roadmap which considers product, technology and production areas.

When the keyword "production" is replaced by "manufacturing", 43 articles were detected, about double the size of the network previously analyzed. Also, most of the articles use a roadmap as a tool to illustrate or manage individual targets such as trends and research challenges in sustainable manufacturing, but not to provide methodological approaches to support firms in SPP. Only Lichtenthaler [LIC2008] 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.

5 Requirements for SPP

5.1 Key findings from literature review

Most articles found in the research of SPP are old articles that deal with classical management tools like the balanced scorecard or SWOT (strengths, weaknesses, opportunities and threats) analysis. In SPP, the strategic part mostly addresses aspects of production planning to improve the performance in production and assembly, such as control tools for the production/assembly line. Mostly SPP deals with a broad range of topics related to management of change, knowledge, human resources, organization, diversity, problems and challenges mentioned in Chapter 1.1. The CIRP community, in particular, is well aware that production has to be reactive and flexible and has to take into account the human factor. But this is rather a determination of an increasing awareness than a methodological support.

Indications from SPP research are the importance of addressing the following points:

- Knowledge and transparency of the functioning of current processes.
- Communication technologies and data management as key enablers for SPP.
- Timely detection and processing of relevant SPP knowledge.

Even if some articles deal with concrete applications, long-term production planning is never treated in a holistic manner. In addition to that, many published theories have not been applied in practice. In summary, we found that there are no methodological solutions to the problems described in section 1.1. More precisely, the biggest research gap is that there is no holistic approach to detect “ideas” (open definition of technology) holistically derived from trends, process them in actual projects, and illustrate or communicate the results. Furthermore, the changing production environment from a linear to an integrated approach needs to be considered in a living integrated process.

The literature review of TRM has shown that numerous publications discuss different purposes of TRM and their applications for specific targets. Frequently, TRM is applied in technology planning to support investments

decisions or resource allocation, mostly from the vantage point of product development. Associated challenges with the implementation of TRM in industry are broadly discussed, such as measuring performance [VAT2012], the systematic update of the roadmap [EIR1997], the effective maintenance and improvement of TRM once it is integrated into day-to-day operations [EIR1997, VAT2012, LEE2012, LEE2007, GOE2008], the active and regular stakeholder involvement [GAU2012a] and the consolidation/integration of different roadmaps (product, production, procurement, etc.) [ORI2009]. But only very few fragments of solutions for overcoming these challenges are proposed in literature. TRM is most often used as a tool for problem application/solving using approaches that are difficult to generalize. No holistic and actionable approaches are mentioned that support companies in planning their pathway from megatrends to real projects and investments [FLA2015b]. By their very nature, these pathways are paved with many uncertainties, which means a TRM must detail maps for roads that have yet to be designed and built.

The following Chapter 5.2 summarizes those identified fragments of solutions that support the development of a holistic process for SPP.

5.2 Process requirements for SPP

As was pointed out above, few publications give practical, usable instructions and/or best practice experience reports of how to set up, implement and deploy roadmapping successfully. Especially in the context of production, no literature deals with holistic process approaches for TRM in SPP. In addition, SPP literature reveals few aspects to take into consideration when constructing a process for SPP.

In the following Table 5-1, key findings from literature are summarized and sorted by process capabilities, stakeholder, decision-making and data management in descending order. In the table's right-hand column, IRP SPP process requirements are derived from those findings. Thereby we use the term IRP (innovation roadmapping) based on our broader view of innovation in production as was explained in Chapter 1.2.

Furthermore, these requirements are described as "functional requirements", i.e., they specify what the process needs to achieve. Requirements are formulated in completing the sentence: "The future process has to …"

To ensure research results and the case study are consistent with these requirements, their coverage is analyzed in section 0.

Key message in this context, including literature source	Process requirements: *The IRP process has to…*
Process capabilities	
• 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 [LIS2008]. • Consolidation/integration of different roadmaps (product, production, procurement, etc.) [ORI2009].	…be adaptable for relevant process elements considering other relevant process.
• As a logical path creator from strategy to implementation treatment in strategic, tactical, explicit and operational tiers [HAK2006]. • Use the master business RM to guide creation of technology introduction plan on the strategic level → further refined at the tactical level and culminates in project plans for implementation [HAK2006].	…ensure the pathway from strategy to implementation and become more and more concrete in subject treatment up to project plans.
• Open technology roadmap which considers product, technology and production areas [SCH2012].	…expand the definition of technology, that planning subjects cover SPP holistically.
• Challenges toward cooperative, responsive manufacturing enterprises are assigned to design, innovation: demand complexity, variability; innovation management [VAN2011].	…consider complex demands = open view of innovation.
• Many affected people; synergies among team members from different departments [GER2007]. • Networking as the most important competitive strength to gain efficiency, collect knowledge and pursue globalization [MAZ2009].	…enable collaborative networks.
• How to effectively maintain and improve the RM once it is integrated into day-to-day operations [EIR1997].	… continuously improve the process.

• Practical guidelines for all RM steps, particularly for the regular updating of an implemented roadmap [GAR1997, PHA2004, FAR2001, LEE2007]. • Systematic update of the roadmap [EIR1997] how and when to review and update a RM. • Keep "alive" on an ongoing basis [VAT2012, LEE2012, LEE2007].	
Stakeholder	
• TRM team has to work together in a unified manner and engage in frequent interactions throughout all steps of developing the roadmap for it to be perceived as credible. So the roadmap utilization increases and becomes a working basis for strategic considerations and decisions [LEE2012]. • Challenges facing cooperative, responsive manufacturing enterprises are assigned to organization, network design, governance and communication (structure/ways of interaction in production networks, information exchange between network members; information sharing, knowledge sharing) [VAN2011]. • Consensus-building process: connects an expected future with a desired future [ZWE2009]. • Why should someone do something if he or she does not know or understand why? The reason for RM is sometimes misunderstood [HAK2006].	…be designed that networking can take place; especially communication, knowledge sharing.
• Adequate attention by management is necessary to motivate the RM team to consider several options, address management's key concerns and justify their positions with a clear rationale [KAP2001]. • Decision aids to improve the coordination of activities/resources [KOS2001].	…ensure that management is aware of the process.
• Complex strategic planning → the stronger, earlier and quicker integration of the planners in product, technology and production is required [SCH2012]. • Integration of suppliers in the TRM process [GOE2008]. • What stakeholders to be involved in RM and how [VAT2012, KAP2001]. • Active and regular stakeholder involvement [GAU2012a]. • Coevolution of products, processes and production	…bring together /integrate experts coming from different functions and areas at a suitable place from the very beginning.

systems needs integrated view of products, processes and production systems during their evolution and changes over time [TOL2010]. • Members include both technical and commercial functions such as R&D, product development, manufacturing, marketing, finance and human resources [ALB2003, PHA2003b].	
Decision-making	
• Adequate technology assessment [HER2009a]. • Assess proposed technology projects → create a balanced technology project portfolio [GIN2006]. • Often it is not clear which alternative to pursue [GAR1997].	…evaluate the planning topics appropriately throughout the whole process.
• Decision-making process must be a collaborative one [IOA2009]. • Collaborative decision-making process [SCH2012]. • Involvement will increase → output used in funding decisions, noting that participants and the attention of decision-makers were involved in the RM effort [KAP2001].	…rate collaboratively at all assessment stages.
• Gather evidence about key decisions and their consistency [KAP2001]. • Challenges facing cooperative, responsive manufacturing enterprises are assigned to decision-making, planning and management (coordination, timeliness, performance evaluation) [VAN2011].	…keep decision-making process of key decisions transparent and traceable, so that performance can be measured.

Data management	
• Operational and strategic technology decision-making needs framework to place information gleaned from explicit data and the tacit knowledge [PET2005]. • Knowledge linked with actual strategic practices in the organization converting future information toward future knowledge [AHL2013]. • Strategic evaluation of different opportunities or threats → business level: comparing vision for the future with current position, and strategic options explored to bridge the gaps [PHA2004]. • Agreed-upon projects should be implemented in a TRM so that strategy and roadmap are linked in a coordinated process [SCH2012]. • Linking R&D investment strategies to business leads to strategic technology alignment RM [GIN2008]. • Detecting important knowledge [COH1990]. • [VAN2011] Production engineering should integrate a rich body of interdisciplinary results together with contemporary information and communication technologies to achieve cooperative and responsive manufacturing.	…appropriately deal with different types of knowledge simultaneously.
• Clarity and transparency of decisions makes it easier to justify the assignment of resources to technology assessment [GIN2006]. • Quality control of data and information used in the TRM process [VAT2012]. • As a logical path creator from strategy to implementation → treatment in strategic, tactical, explicit and operational tiers [HAK2006]. • Use a master business roadmap to guide creation of a technology introduction plan on the strategic level, which is further refined at the tactical level and culminates in project plans for implementation [HAK2006].	…ensure consistent data management (data quality) in all levels.

Table 5-1: IRP SPP process requirements

Part II:

Development of an Innovation Roadmapping Process Approach to Strategic Production Planning

6 Conceptual framework of the research

6.1 Research question

Following from the scope detailed in Chapter 1.3 along with an awareness of the identified process requirements for SPP as in Chapter 5.2, companies have to find structured, holistic ways for SSP. The central research question is:

> ***How to create a structured holistic and innovation roadmapping process-based approach to SPP and implement this process in a corporate industrial environment such that it successfully enables product manufacturing innovation in practice?***

Given the particularities of SPP and TRM in SPP characterized in the literature review, the question is how such a holistic approach will assist manufacturers in innovating holistically in the long term more efficiently and effectively than they do today. This leads to the following sub-questions:

1. What process design guides production departments from megatrends to projects becoming more and more concrete in a systematic, holistic and traceable way [FLA2014]?
2. What decision gates are needed to assess planning topics appropriately throughout the entire process?
3. How can process design ensure all topics relevant to SPP (technology, process, organization, etc.) and associated dimensions are taken into consideration?
4. How can an integrated structured process design with stakeholder integration be ensured?
5. How can data management create traceability and consistence in data?
6. How can the approach be implemented in a company in a verifiable way?

6.2 Research objectives

The principal focus of this thesis lies in creating an SPP process that answers the six above questions. As explained in Chapter 1, TRM is a fundamental element around which the process shall be designed. Furthermore, the process must be able to be implemented within existing process landscapes of production industries with reasonable effort and in a reasonable time frame. To validate the generic IRP SPP process, the author's corporate environment was selected as a practical case study of an implementation. The company is characterized by a strong process-orientation, typical for the automotive supplier industry, particularly in Western Europe.

Based on this main focus, the research objectives can be defined as follows:

Creation of a generic strategic production planning process, as a central living decision-support tool in Industry 4.0 with the following key characteristics:

- It shall capitalize primarily on internal knowledge, yet be open for the integration of external knowledge.
- It shall network internal stakeholders with diverse expertise and organizational functions.
- The process shall be measurable to assure assessment of its performance and continuous improvement.
- It shall be deployable in various industrial settings and verified by a case study.

6.3 Research context

The research question is approached by the author in the role of a researcher working as a full-time employee within the industrial environment of the German automotive tier-1 supplier ZF Friedrichshafen AG. More precisely, within the division of commercial vehicle technology, the author was part of a team that deals with technology development in the production of transmissions for commercial vehicles, such as trucks and buses. Consequently, the author had access to real industrial terrain practices and know-how throughout the entire research process, which has led to the strong practical orientation of this thesis. The company context is described in more detail in the case study in Chapter 8.2. At ZF, the subject, which has high strategic importance, is located on the business unit (BU) level. Therefore, research findings are applicable to similar situations in other manufacturing firms.

6.4 Research methodology

In order to examine how an SPP process model could look like, information from both literature and industry experience were utilized. In a first step, IRP SPP process requirements were derived from a detailed and systematic literature review in the areas of TRM and SPP. Based on this, our research hypothesis is that we can address these requirements best by an approach based on processes and methods from integrated design research [TIC2004]. A focused literature analysis in this area led to additional IRP SPP process design requirements, as well as a rough process architecture. The detailed IRP SPP process design that followed this step can be considered as the key contribution of this thesis. The generic and adaptable approach has been validated at ZF and the IRP SPP integrated into ZF's process landscape. Figure 6-1 illustrates this approach and refers to the respective chapters.

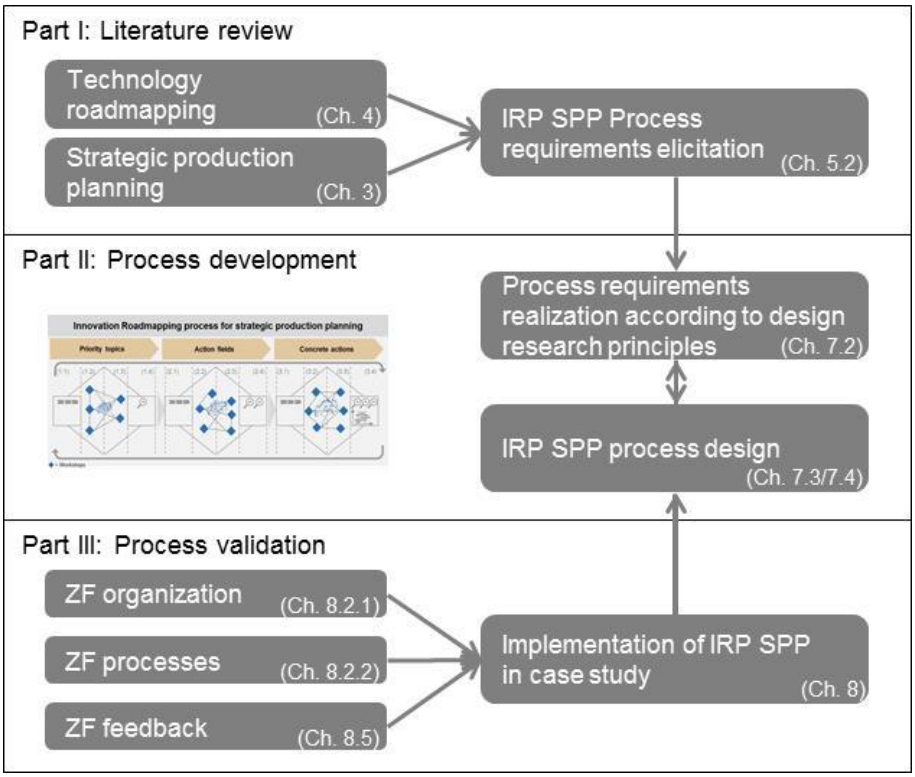

Figure 6-1: Conceptual framework of the research approach

7 Innovation roadmapping process for strategic production planning

7.1 Procedure of process development

For the detailed IRP SPP process development, the identified process requirements must be considered. Our observation is that they share many characteristics of the requirements for creative integrated design processes for new products, services and processes (NPD) [FRA2014, KHU1998], e.g.:

- Outcome of the planning: unknown at the beginning of the process.
- Artifacts to be designed: highly interdisciplinary in their nature, requiring experts from several different trades to actively participate in the process.
- Relatively few key requirements for the process and the final outcome at the beginning; identification and formalization of requirements and constraints are part of the design process.
- Outcome of the process: subject to evolution, driven by changes in requirements as well as the changing context [FLA2016].

Therefore, our main idea is to find a means to carry out SPP as a creative integrated design process, bringing together experts from fields that have some stake in future technology use in the organization [FLA2016].

The following chapter 7.2 points out the specific literature review findings in integrated design research guided through search fields.

Chapters 7.3 and 7.4 present the design of IRP SPP, including detailed process steps and implementation aspects.

7.2 Literature review

We scanned design research literature to identify approaches to tackling challenges linked to the four basic clusters: process capabilities, stakeholder, decision-making and data management. The aim was to find concrete tools and

key success factors that can be considered for the design of the IRP SPP process. To find approaches for taking into account every single IRP SSP process requirement, the search fields shown in Figure 7-1 were investigated.

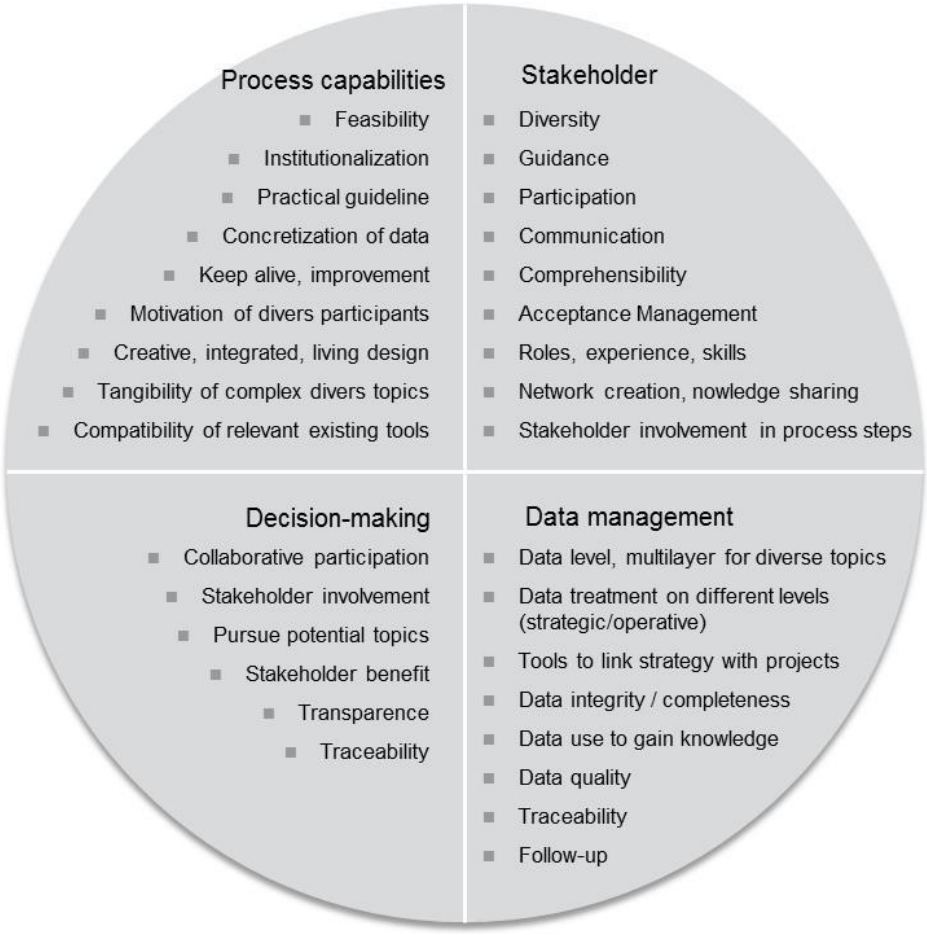

Figure 7-1: Search fields in integrated design research

The following chapter gives an overview of relevant research findings sorted according to these categories.

7.2.1 Key findings: Process capabilities

To handle the complex context of SPP, Francalanza et al. [FRA2014] proposes treating factories as products in comparing approaches of systematic “product design” and “manufacturing system design”.

Cooper [COO2014] provides an agile stage-gate process approach with the flexibility and agility enabling requests for change in process feedback-loops. The actual planning is continuously evaluated through an interdisciplinary team that takes a holistic view as to the plan's compliance with requirements. The creative problem-solving process (CPS), first discussed by Alex Osborn in the 1950s, provides a strict model for generating ideas systematically. Crucial elements of this structured creative process are: fact-finding, problem- finding, idea-finding, solution-finding and acceptance-finding [OSB1953]. In the progression of the CPS model the beginning steps were expanded to include "problem sensitivity" and "mess or objectives", and in the end steps by "plan" and "action" [NOL1976]. Every step includes a divergent- and convergent-thinking section. The aim is to generate many ideas and to then choose the most attractive ideas to bring to fruition. Isaksen et al. [ISA2000] considers four phases of CPS in his CPS Version 6.1. The first integral part of the CPS is the visualizing of challenges through the problem to plan the solution. Not only is the problem discussed but also the unsatisfactory situation, which must be understood in its complexity. By this creative step, the problem is analyzed, localized and limited to then generate ideas, prepare for action and plan the approach in the next three steps of the model.

The concept of an open way of problem solving proposed by Geschka [GES2010], illustrated in Figure 7-2, highlights the importance of divergent and convergent thinking in problem solving.

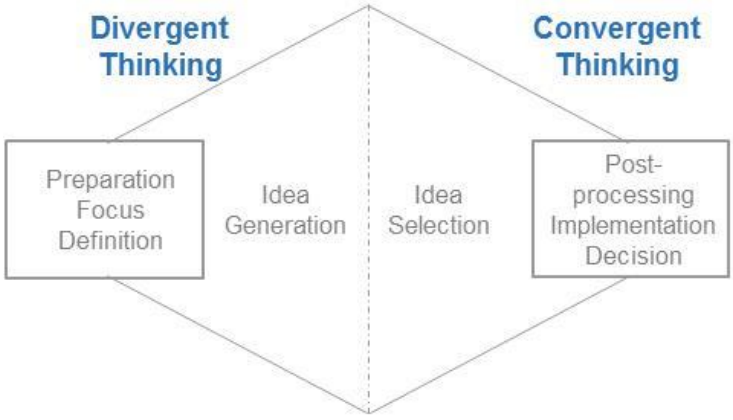

Figure 7-2: Concept of an open way of problem solving [GES2010]

In the OPM (open problem solving model) cycle, Geschka extends the simple divergent and convergent thinking. Before divergent thinking can happen, the problem has to be understood and tasks have to be demarcated and precisely defined. By following this preparation step where planning topics are expanded in dimensions and dependencies, it is more certain that idea generation takes place with the right comprehension. In this step of ideation, all ideas are

allowed and the search space is defined. In the idea selection step in turn, the selection procedure is quite strict as the ideas must be feasible, effective and economically viable. The cycle concludes with the decision on how to proceed further with the chosen idea.

Moreover, the methodology can be used at any point in time in the problem-solving process. The greatest value lies in problem clarification, as it is an integral part of the OPM model. To solve a problem up to solution implementation requires several cycles. In the first cycle idea directions and solution approaches are found, whereas in the next cycle they must be solidified through in-depth studies of the content or demarcation and definition of further tasks. The more complex a problem is, the more cycles have to be processed in parallel or successively, as illustrated in Figure 7-3. The ideas chosen in one cycle are the starting point of the next cycle. In between information should be gathered and definitions have to be made [GES2010].

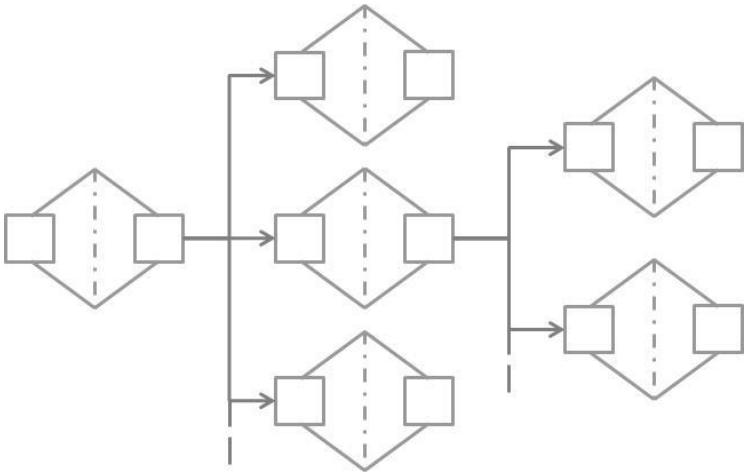

Figure 7-3: Parallel and successive OPM cycles, Geschka [GES2010]

A combination of structure and flexibility in small stages of activity of divergent and convergent sub-phases is needed to enrich the quantity and the quality of ideas [JAC2012, DUP2008]. In addition, within the small stages the right effective and efficient tools/techniques have to be chosen that bring flexibility, agility and nimbleness [LUT2014]. Within the process, gates help to decide further proceedings with topics [COO2014, WUE2014, NIK2002, GES2010].

Furthermore, SPP problems require an integrated cross-functional approach considering holistic and cross-functional perspectives [DUP2008, MOS2008, LEG2010]. In addition, creative sessions allow a holistic view through the participation of relevant stakeholders [FRA2014, MOS2008].

In Phaal's S-Plan and T-Plan Fast-Start Roadmapping methods he suggests an integrated agile one-off problem-solving tool consisting of the three steps, preparation, implementation and follow-on [PHA2013]. A central element is facilitated group work sessions where the focus is encouraged to be on the most important issues. In addition, workshops should be planned well in advance and consist of group-based activities. A key requirement is participants' experience and knowledge with different perspectives that is captured, shared, organized and developed into concepts through structured frameworks (charts, templates to guide activities), clear steps and summarized outputs. The overall workshop agenda needs to be designed to meet the agreed-upon aims, with the time available broken down into logical steps. In this way, strategic dialogue is facilitated because participants are empowered to contribute and interact with one another. Takouachet et al. [TAK2014] also highlights the importance of facilitated creativity session through planning, organization and guidance of the participants in group work in order to help them be effective and reproduce relevant results. Through good moderation, ideas can easily be generated/captured, collaboration can take place in real time, structuration and organization can be flexible, and the focus of the workshops can be re-adjusted at any time. This has a great potential for improving group interaction and outcomes. Creativity in sessions is encouraged by a good atmosphere and corporate culture [LEE2015]. The process is tolerant of diversity, enabling rapid progress in complex business and organizational contexts in the sense of being flexible, rapid, efficient, scalable and problem-focused. It is independent from individual creative techniques as it always follows the four integral cycle steps in which creative techniques are appropriately combined [PHA2013, LUT2014, TAK2014].

A crucial aspect to keeping the process alive is to provide fixed steps for improvement. Through lessons learned in the first run, formalization and routines adapted to the specific sub-phases and to the specific contexts makes continuous improvement possible [JAC2012, PHA2013]. In addition, continuous communication within the network keeps the process alive [DUP2008].

7.2.2 Key findings: Stakeholder

Freeman introduceed stakeholder integration into the management literature [FRE2004]. He defines a stakeholder as "any group or individual who can affect or is affected by the achievement of the organization's objectives" [FRE1984] in the R&D and innovation management context [ELI2002, SMI2009]. Stakeholder analysis that precisely defines who stakeholders are is compulsory for innovation projects to gain more validation and significance [ELI2002, STE2009, GAU2012a]. It can be motivating to involve internal and external stakeholders [SHE2006].

The main benefits that can be derived by incorporating diverse stakeholders are information diversity when knowledge, experience and expertise are successfully exchanged and combined [VAN2004]. Diversity delivers benefits by reinforcing the creativity, the workforce, top management's attention, decision-making, communication and the innovation culture [WAG2010, LEE2015].

Through stakeholder involvement knowledge exchange is enforced by fostering trust, communication, information- and knowledge-sharing, cooperation and coordination, commitment, transparency and flexibility [SJO2015]. However, the variety of perspectives and pool of knowledge require adequate management [WAG2010]. Garcia et al. [GAR2015] as well underlines the necessity of having an organizational process in which any team conflict that arises does not weaken the positive effects of educational diversity at the expense of the negative effects emerging from gender and skill diversity. In addition, the process needs clear strategic directives and clarity on the expectations (not too generic directives and criteria, and not too much detail) to create understanding and feasibility. The level of specificity depends on the specific sub-phase and most likely also of the quality and experience of the team involved [JAC2012]. Practical guidelines make the process easy [PHA2013].

The ideal open innovation specialist is characterized by the ability to manage and accelerate the inflow and outflow of knowledge through skills in intellectual property management, negotiation, entrepreneurship, leadership, team-working, multitasking, problem- solving, virtual collaboration, internal and external collaboration, trust, communication and networking skills [POD2015].

The integration of different views on the observable objects in the whole process promotes the identifying of requirements and constraints in a holistic manner [ZWO2007]. Thereby, it is crucial for stakeholders and decision-makers to maintain a trustworthy relationship to ensure the stakeholder network in a company is a source of sustainable competitive advantage and innovation [LIN2015]. Individuals more connected within the network led to a higher proportion of high-quality ideas [BJO2009].

An important aspect of process design is how the process is kept alive. In this context participants have to profit from the process results (findings/output/exchange) to be convinced to participate further. Participants need to see their own benefit. Stakeholders benefit from an information network as a result of working collaboratively [DUP2008]. Furthermore, a process owner on high hierarchical level must bring together and motivate the various representatives. In addition, a core team must be built to put the process on solid footing. Members must meet on a regular basis with frequent interactions to work together on topics revealed. Topics are discussed in-depth and steady

progress is made through preparation and follow-up activities. In addition, the core team has to work together in a unified manner, so that decisions are made with overall agreement and a holistic view. They act as internal promotors [LEC2015]. Moreover, the process needs the full support of senior management and full participation of managers at all levels to stay alive [TRK2010, KAP2001].

7.2.3 Key findings: Decision-making

Decision-making is a crucial element of the future process. Actionable directives, formal decision criteria and decision committees lead to a good final decision, while avoiding unwanted and unconscious individual decision-making as well as filtering by individuals [LEC2015, JAC2012]. Through implementation of explicit final criteria and involvement of the whole team in the final decision process, efficiency is achieved and the impact of individual biases is reduced [LEC2015]. Effective and efficient evaluation criteria have a vital role in the different sub-phases and form the very basis for any managerial decision [MAR2011]. Evaluating all the various decision criteria requires much varied expertise and points of view, which is why multifunctional group decisions on different levels are important [JAC2012].

A central characteristic of decision-making structures is the extent of their centralization [CSA2012]. Centralization can be defined by the concentration of power and decision-making among a small circle of people within the organization [HAG1970]. In centralized structures, information and authority is less diffused and fewer conflicts occur. This reduces the need for information-sharing and consensus-seeking and therefore enhances decision-making speed and efficiency [PFE1981, STA1981]. In the sense of a core team, the process is governed and managed through a small team of senior managers that steer and review progress and outcomes [PHA2013].

However, decentralized structures might be more effective in uncertain environments [SCO2001]. Lingens et al. [LIN2015] recommends independent democracy in decision-making in terms of knowledge transfer, stakeholder cooperation and robustness of stakeholder cooperation. However, it tends to induce high costs [LIN2015].

As knowledge and decision power are interdependent key resources for decision-making [BAU2003, PFE1978], relevant stakeholders need to be identified and involved. Employees may have different perspectives based on their positions which may influence their decision-making [PAR2007]. Power determines the outcome of a decision [FRO1999]; therefore, management needs to participate in decision-making. But as Thompson [THO1967] mentions, individuals in highly discretionary positions seek to maintain power equal to or greater than their dependence on others in the organization. If management

participates in decision-making, the complexity of process and topics is reduced because management commits itself and recognizes competing interests related to the assessment system. In addition, management draws attention to topics of mutual value [MAR2011].

Convenient decision-making techniques have to be chosen in defining criteria for prioritizing to achieve a comprehensive decision quickly [KOS2011, MCM2003]. Moreover, the decision-making process must be collaborative [IOA2009, SCH2012]. The actions of decision-makers can be better understood by involving stakeholders and having dynamic consultations of specific topics. In addition, the decision-making process doesn't have to be too complicated or require too much effort. Furthermore, it is important to gather evidence about key decisions and their consistency [KAP2001] to enable the communication and conversion of ideas [NEU2013].

7.2.4 Key findings: Data management

To provide a multilayer view, topic network, data quality, traceability, etc., data must be organized in a central tool. Gausemeier et al. [GAU2012b] underlines the importance of connecting relevant information in a central concept. Several software packages have been compared in terms of linking of topics, visualization in multiple layers (trends, concrete actions) and visualization of roadmap:

- ITONICS (PoC),
- Qmarkets (trial installation),
- SAP Innovation Management (trial installation),
- Hyve (trial installation),
- Hype,
- Sopheon,
- HNI (Heinz Nixdorf Institute).

ITONICS was the best provider with its applications for ideation platform, roadmap visualization, trend radars, foresights and campaigns where workshops can be documented and linked [ITO2017].

Applications are the following, taken directly from the company website [ITO2017]:

- ITONICS Scout: Identify and analyze trends and technologies in an automated manner. Highly sophisticated algorithms aggregate information from various sources in real-time, such as patent databases, RSS feeds or scientific publications.

- ITONICS Radar: The solution for strategic and operative environmental scanning in complex business environments. Analyze and assess corporate environments from various perspectives.
- ITONICS Ideation: Integrate all ideation activities, such as gamification, stage-gate, campaigns, collaborative ranking and rating, concept co-creation, open innovation, etc.
- ITONICS Roadmap: Identify inconsistencies and gaps in your technology and product development through numerous analysis possibilities. Observe markets, products, services, technologies and resources in an interactive roadmap.

Besides the above described data tools the CoCa tool from Pod et al. [POL2007] delivers a further aspect to data management considering collaboration aspects in context of coordination. It focuses on the analysis of the collaboration tracking all collaborative events and project content in design activities (Figure 7-4). This helps to understand activities and collaborative practices of the company.

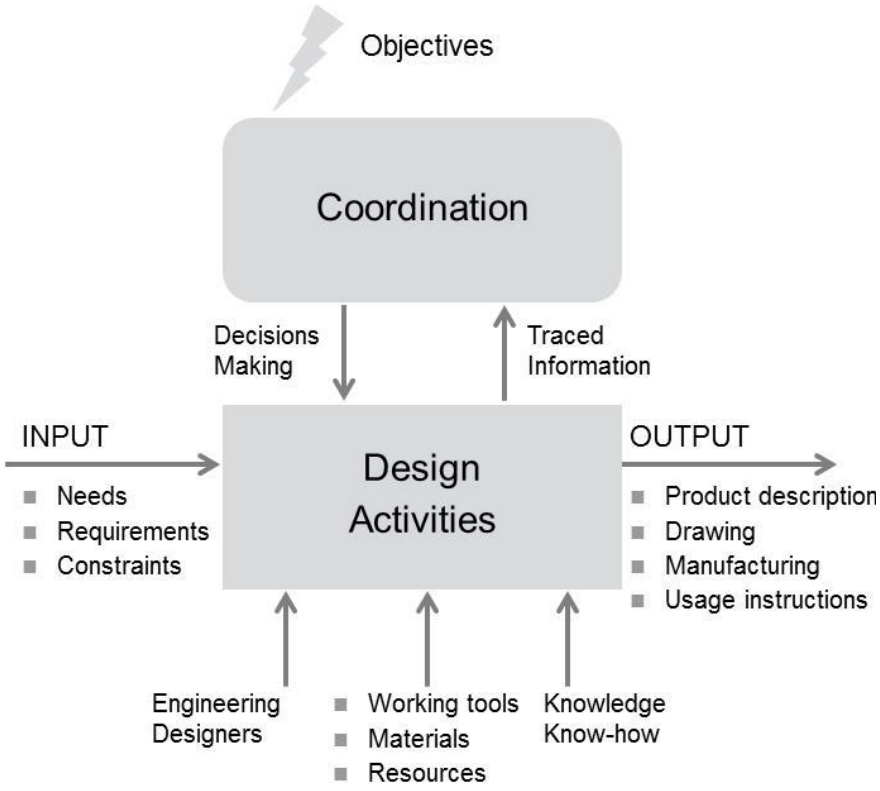

Figure 7-4: Control of collaborative aspects in projects [POL2007]

7.3 Implementation of IRP SPP process requirements

Based on the IRP SPP process requirements, the following hypothesis shall be used to design an IRP SPP model and validate it in the industrial setting of ZF:

Innovation roadmapping can be facilitated effectively and efficiently through the structured networking of experts from several different domains in joint creativity/design sessions for strategic planning carried out over the whole planning process.

Methodologies from design process development (especially findings from 7.2) will therefore be transferred to create an integrated creative process in SPP.

7.3.1 Process capabilities

While it is quite simple to identify the necessity of SPP to react to trends, it is quite difficult to implement projects that really contribute to trends. In this chapter, the process capabilities necessary for going from megatrends to actual projects is described and called Innovation Roadmapping for Strategic Production Planning (IRP SPP).

Based on Geschka [GES2010], the central design element of "problem solving in SPP" is the model of **four sub phases** illustrated in Figure 7-5.

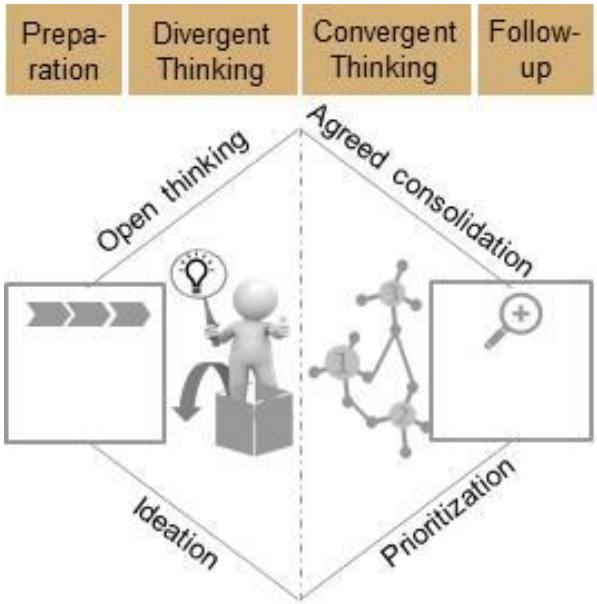

Figure 7-5: Basic ideation process model based on Geschka

The phases function as gates to handle topics systematically:

- Preparation: Systematic steps that achieve the gathering of relevant input as completely as possible. All necessary information is considered and distributed in suitable forms.
- Divergent thinking: Out-of-the-box and Design Thinking [BRO2008] related to topics clearly defined in creative sessions.
- Convergent thinking: Topics are consolidated and/or prioritized in agreement with all participants with clarity as to how to proceed with each topic generated during the previous phases. SPP topics are interconnected subjects that depend on many factors and other trends. Therefore, it is important to decide which subjects to pursue in which depth and scope.
- Follow-up: Specific focus-setting on topics for further development, relevant provision of information through structured comprehensive summaries of work progress. The output of prioritized topics serves as input for the further cycle. The roadmap as the result of the last output provides an overview of generated knowledge that is particularly vivid and easy to grasp [ZWE2009].

As illustrated in Figure 7-6, the IRP SPP has been designed as three opening and closing funnels, namely cycles, where production is guided from megatrends to actual projects to refine an increasingly concrete view of challenges and opportunities. The process is designed to start with megatrends as initial input and deliver projects for the TRM roadmap as major output.

1. Cycle 1 deals with (mega-) trends where production has to derive relevant topics for themselves. The aim is to define individual, specific production trends, namely priority topics to avoid ambiguity in the use of the term “trend” and to define important topics.
2. Cycle 2 derives action fields for the topics identified in Cycle 1 through an integrated holistic understanding with associated challenges. In this way, priority topics are rendered tangible and become more concrete.
3. Cycle 3 refines concrete actions leading to projects that contribute to the addressing of the action fields. These projects are described in a unified format and integrated in the roadmap. In this way, priority topics become more and more concrete and complete in terms of processing.

The numbers of process steps in Figure 7-6 are meant to serve as orientation for the detailed process description (Chapter 7.4) and the application in the case study (Chapter 0). In addition, the blue diamonds symbolize a typical workshop series and no obligatory session. Depending on capacities and organizational culture more or fewer workshops can be planned.

The big arrows throughout the entire process illustrate the intended feedback-loops in all steps of the three cycles and are oriented on Cooper's agile stage-gate approach. The IRP SPP consists, in a main structure, of three cycles that represent three stages with gates and within the cycles a further four steps with additional stages and gates. Steps in process are described roughly and are adaptable depending on the planning topic. The process is not inflexible, but allows iterations in all steps. Because of the universal applicability of the process for all planning topics in IRP SPP, the scope of work is incalculable and the process is structured to be agile [COO2014]. Furthermore, in order to leverage the IRP SPP's universal applicability in different industrial organizations, it is important to highlight that the process has to be adaptable enough to take over related existing successful practices and process steps.

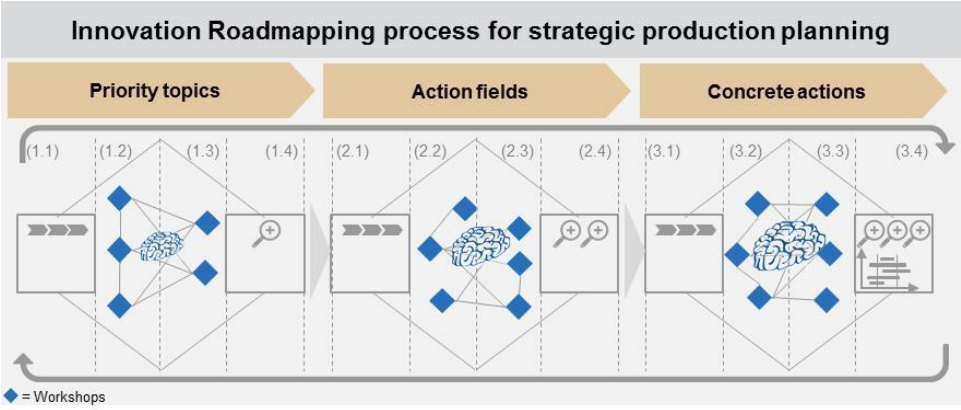

Figure 7-6: IRP SPP Process Model

Because topics in SPP are interdependent and interconnected, it is not a linear process with only one "path" of subject. Therefore, multiple parallel paths should be taken to consider and allow simultaneously action in the complex interlocking of topics. Due to requirements and constraints in time and resources, it is not possible to choose one topic on the high level of priority topics and proceed through to concrete actions that holistically cover the context. Priority topics cannot be processed completely, but become more and more complete because all dimensions and possibilities for the topic are taken into consideration [GRE2007]. Thanks to systematic evaluation gates and varied viewpoints in every cycle, the process will uncover projects with the most potential that are probably the most advantageous for the company. In this way, nothing is left out because documentation occurs at every step. In addition, regular processing is based on previous findings, especially results from actions taken in the first iteration (formal or informal), and work progresses along the different concretization levels. Furthermore, in all steps, processes and

disciplines are refined to encourage future iterations along with process adjustments. Through iterations, established relationships become stronger.

Parallel investigation paths are not outlined in Figure 7-6, but are intended and illustrated in Figure 7-3. The brain becoming greater symbolizes the knowledge gain with increasing concretization level of topics.

A prerequisite for a living process is its regularity, wherein priority topics are updated at least once a year and action field/concrete action workshops are held approximately every two to three months [OZA2015]. The actual workshop frequency and rhythm shall be adapted to the organizational culture primarily in terms of the organization's capacity to organize and capitalize on interdepartmental creativity workshops.

The established process/discipline will result in more efficiency and effectiveness in every single step. A process owner at a high hierarchical level brings together and motivates the representatives coming from procurement, product development and production. To put the process on a solid footing, a stable core team shall be composed of senior managers and domain experts coming from different disciplines and organizational units. For SPP facing Industry 4.0 challenges, we recommend product development, production, procurement and IT.

This core team has a significant importance for the process's success and performance. Members meet on a regular basis (e.g., every one to two months) with frequent interactions to monitor and control progress/outcomes on topics brought up and further refined in the IRP SPP. They make collective decisions about which topics shall be investigated in the upcoming IRP SPP workshops/activities, as well as about the required stakeholders to be invited and prepared for participation. They should ensure the steady progress of topics as they run through the process. Most importantly, they must act as internal promotors to drive the process forward and permanently expand its roots in the organization, as well as continuous evaluate and seek improvement through the learning cycles.

To work on topics, members meet in creative sessions in workshops that serve as processing types in the divergent and convergent steps, shown in Figure 7-5 as blue diamonds. Workshops are individually designed depending on the purpose and scope. In creativity sessions, ideas are generated on a different level of concretization depending on the cycle. Each topic requires appropriate individually chosen creativity techniques to activate participants. In addition, participants are guided so they always know what is going on. Therefore, participants and the workshop are individually prepared to make the best use of the little time available. Workshops should take longer in the beginning, so that participants can be sufficiently informed to have the target in mind to efficiently work in the creative session, make ideation and consolidate identified ideas in

plenum. If all do not attend the first meeting, valuable time is lost in a next workshop when new participants have to be brought up to speed and others have to hear again about the target of the divergent phase and already generated topics or decisions made. In addition, it is rare that the same employees participate again. In group work, it is recommended to have three to five people per group, so that groups are not too big and the work is done efficiently. Overall, a workshop agenda that meets the agreed-upon aims with a structured framework and clear steps illustrated on charts helps to comply with a suitable time schedule for adaptable and flexible working packages. If possible, it is advised to bring participants into a close, new environment without their smartphones, so that nobody is distracted. In the early stages of IRP SPP, full-day workshops, if possible, are efficient because work packages cannot be reduced. Generated ideas must be documented completely and clearly. Finally, output summaries document the work progress. All steps are problem-focused with scope and schedule coordinated. All creativity (divergent) and evaluating (convergent) sessions are moderated to help participants expand their minds to be able to get out of their boxes (i.e., contexts) [TAK2014]. Moderators can also guide the discussions with a neutral and unprejudiced opinion through a tight time schedule.

What is crucial for the IRP SPP is to have the right participants be involved continuously. A collaborative network is enabled by integrated design, meaning stakeholder involvement occurs throughout the process and is established in the core team. Depending on workshop purpose, the team composition must be appropriate for enriching ideation. In the context of innovative product development in large industrial companies, procurement and production have the most influence on innovation and transformation to Industry 4.0 and, at the very least, must be involved among other possible perspectives. Necessary additional viewpoints can be brought in from controlling, marketing, R&D, human resources, etc. Chapter 7.3.2 goes into more depth considering stakeholder involvement along the process.

Chapter 7.4 contains a detailed description of the process steps with inputs, outputs from activities, as well as characteristics and recommendations.

7.3.2 Stakeholder involvement

Because Industry 4.0 uncovers a variety of planning topics in SPP, the interdependencies of production with product development and procurement must be considered in stakeholder involvement. In particular, a holistic view of planning topics to cover is ensured when experts from various sectors are involved. As has been detailed in this thesis, product development, procurement and production are very important stakeholders in SPP; but depending on the purpose, participants on the horizontal plane (management) and vertical

(engineers, machine planning, controlling, etc.) should be involved to enrich the creative session with their viewpoints and experience as well. In the first cycle, participants need to have a high strategic overview. In the third cycle, participants need to have concrete special knowledge in terms of topic, interdependencies and existing tools to create concrete actions.

The variety of perspectives and pool of knowledge is managed through clear guidance in all sub-phases, especially in workshops, advance preparation, balanced composition of teams, and the right choice of participants based on their skills (inflow and outflow of knowledge). This controlled diversity of information enables an exchange and combining of knowledge, experience and expertise. In addition, creativity, workforce, top management attention, communication and innovation culture is reinforced. Networking results in a higher proportion of high-quality ideas. Furthermore, the holistic view gained by integrating different views in terms of functions and economic, ecologic, and social environment reveals varied ideas in SPP.

The regular and active participation of decision makers (management from several hierarchical levels) is considered of utmost importance, since they can give valuable inputs from their managerial viewpoints and also better understand the backgrounds and reasons for collective decisions. Such collective decisions are particularly important when it comes to setting the right focus when determining priority topics. Furthermore, management can experience the progress that has been made on individual topics even in periods where concrete outputs may not yet be available. They get a deeper understanding of important subjects in specific production areas to better coordinate resources and activities and obtain regular information about results and core team activities. Active management participation will also have a positive effect on the involvement of employees for many reasons, however in particular for the occasion of communicating and collaborating across several hierarchy levels.

Visible benefits through collaborative work on important topics creates a network of stakeholders with trustworthy relationships. Participants profit from the process results (findings/output/exchange) and the knowledge exchange, as illustrated in Figure 7-7. In the IRP SPP workshops, participants network through connections with everyone in the workshops. Moreover, the network intensifies through exchanges out of, but initiated through, IRP SPP.

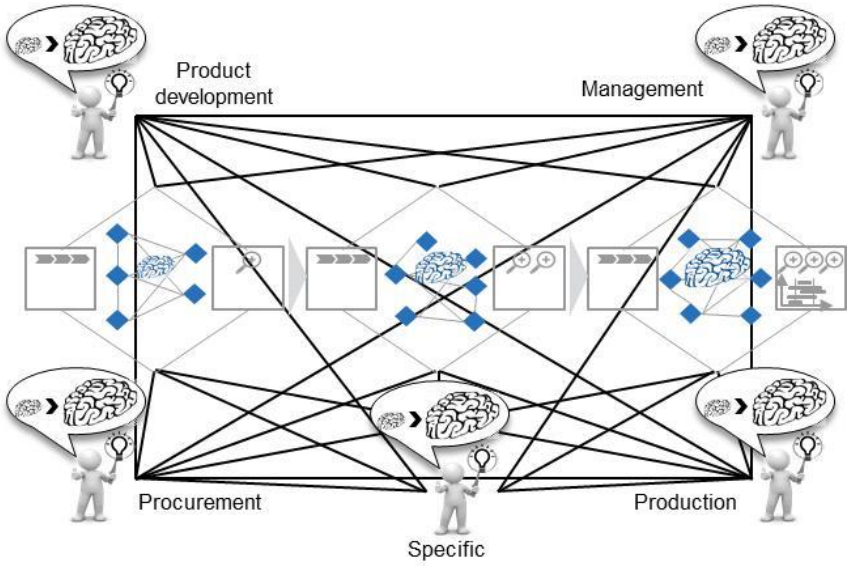

Figure 7-7: SPP IRP Networking

The core team and the WS participants must work together in a unified manner, with frequent interactions in all process steps, so that the roadmap utilization increases and becomes a working basis for strategic considerations and decisions. To enable networking, IRP SPP has a communication strategy for the sharing of information; especially output is used/distributed. In addition, process output is credible due to transparency, history of data and association of topics with other topics/trends (see Chapter 7.3.4).

7.3.3 Decision-making

Through structured decision points all the way down, little capacities in IRP SPP can be reasonably distributed in a comprehensible, transparent and traceable fashion. Decision-making is distinguished between content decisions and process decisions and illustrated in Figure 7-8.

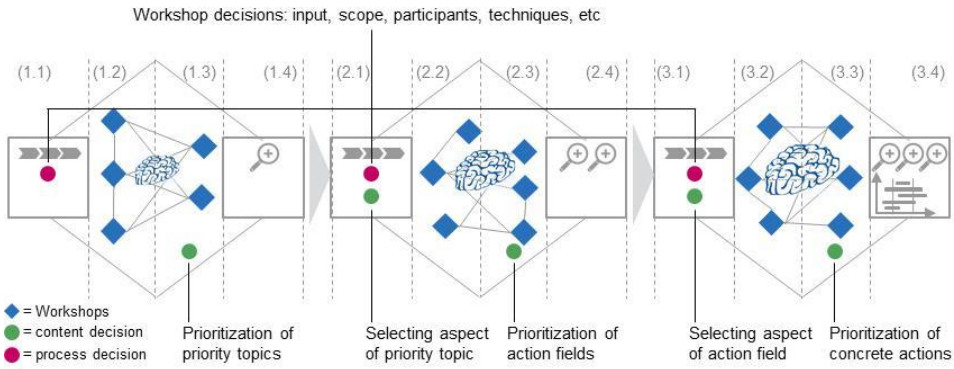

Figure 7-8: Content and process decision-making in IRP SPP

Content decision points (green points) are positioned where associated costs must be coordinated to further prioritize or concretize topics. Before topics are further investigated, a decision must be made on which aspect of topics to pursue. Especially in the convergence steps, decision-making should be done with formal decision criteria and the involvement of the whole workshop team. Convenient decision-making techniques have to be chosen to define criteria for prioritizing and to achieve a decision quickly and comprehensibly. Through this multifunctional group decision-making, different types of expertise and points of view contribute to the rating. In addition, a holistic assessment that includes the various competing concerns is assured. The independent democracy in decision-making enforces knowledge transfer, stakeholder cooperation and robustness of stakeholder cooperation in uncertain environments. In addition, participant motivation in decisions increases, because in the collaborative setting it is clear and visible that decision-making impacts the work. If participants are allowed to choose the topic they are interested in, benefits result because the topic is researched in scope and depth. But decision-making requires clear actionable directives, so that it is guided, comprehensive and decisions are agreed-upon. In addition, the decision-making process must not be too complicated in respect to requiring too much effort, but with simple indicators. To avoid wrong decisions, management needs to take part but must not have more power than other members. Industry 4.0 and global SPP problems in the first two cycles are very connected and interdependent. Important points of view are production, product development and procurement, as they have the most influence. At this stage topics can only progress with a holistic view and approach. If needed, controlling, marketing, etc. should be involved as well in the sense of offering dynamic consulting to topic-specific decision-makers. In Cycle 3 it depends more on the topic in which stakeholders are needed. Due to the level of concretization at this stage, very specific processing can be completed, in which case it's better if more viewpoints are considered at a lower level.

Process decisions (red points) are made in the preparation steps. In the input steps workshop planning decisions must be made. In addition, appropriate input, participants and utilized techniques have to be determined. Also, decisions have to be made on the number of workshops to be held and what working packages in the divergent and convergent sessions can be combined into how many workshops. Process decisions are made in the core team.

All decisions gather evidence through the documenting of decision-making, which also records the people and the reasons behind their evaluations. As a result, further processing is enabled and participants understand decisions and the decision-making process. In addition, evaluation can take place on previous findings. Through decision-making with appropriate criteria concerning competing parallel interests, complexity is reduced. The second advantage of documentation of decision-making is the ability to trace decisions and to reproduce and understand decisions. With pre-determined assessment tools, decision criteria throughout the process of decision-making can be compared in future projects as to the speed of decision-making and simplicity of reaching agreement.

7.3.4 Data management

The choice of a data management system is very context-dependent in terms of existing systems already used in the company. Therefore, the information system of IRP SPP needs to be integrated in existing data management systems as much as possible. There is no single solution for an IRP SPP data management system, however there are certain IRP SPP elements that have to be supported by the information system (Figure 7-9).

Data created in the IRP SPP need to be presented in several different levels of detail easily and traceably, both on a strategic level (priority topics) and on a concrete level (concrete actions). High priority topics need to be illustrated with their dimensions, dependencies and processing status. Conversely, concrete actions must be illustrated at a lower level with documented level of concretization and historical progress. The linkage to priority topics must be illustrated to reveal priority topics as they become more and more complete.

A “production roadmap” must be generated from the data entered. In addition, the roadmap has to illustrate the prioritization of concrete actions through a time line and an axis of relevance to show which topics have the highest potential at first sight.

On a central shared network drive (with password protected access), working documents (e.g., previously given presentations, studies used in the preparation/conducting of workshops, progress reports), minutes, management summaries, consistent bi-directional traceability of all results (all steps)

inclusively stakeholder must be available for all participants and relevant employees. In particular, the output of the process steps must be detailed in summaries to keep the process flow comprehensible.

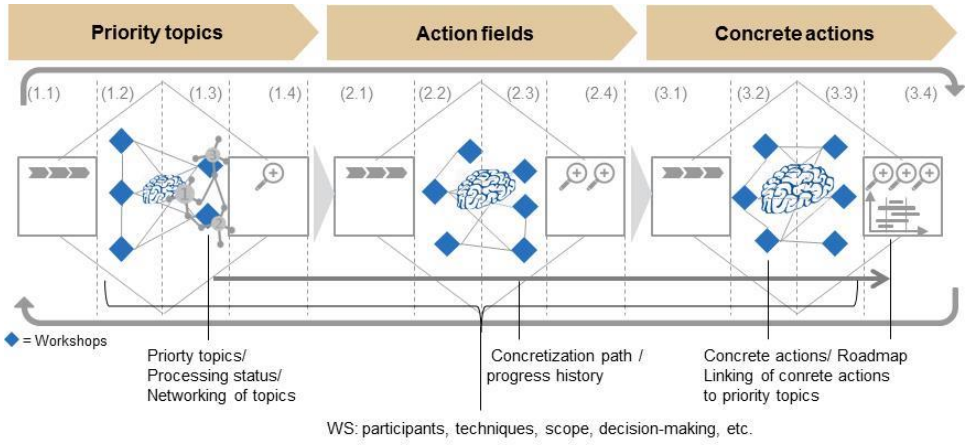

Figure 7-9: Visualization elements of IRP SPP data management systems

A good data management system also provides a foundation for continuous communication across the stakeholder network. A central data pool provides stakeholders with workshop minutes and documents of work in progress. Existing data can be used and developed to inform future-oriented knowledge.

Data systems in the workshops have to be simple with known data tools, so that employees are not burdened by needing to learn a new system. In accordance with the continuous improvement mandate, the process workflows need to be improved in every loop, e.g., through templates or standardizations which support the workshops in documentation and visualization. Tools must ensure that in the next loop it is easy and efficient to work on previous findings. Thorough documentation in the workshops saves time, ensures traceability and helps participants to clarify their ideas.

Topics in the SPP are appropriately treated and processed holistically and completely. In a multilayer view of data, topic network interdependencies and links to relevant documents are modeled. To obtain good results, participants need to process topics holistically with data completeness/integrity, if possible. Therefore, topics should be processed through the course of regular work with the right point of view. Work progress should be documented over time so that it can built upon along with existing initiatives and processes. The level of detail of planning of strategic actions and projects increases downstream the IRP process. Hand in hand with this goes the increasing level of knowledge and insight of the involved stakeholders.

Based on the aforementioned data management needs, our recommendation is to use a software solution like ITONICS that provides an ideation platform, roadmap visualization, trend radars, foresights and campaigns where workshops can be documented and linked.

In terms of collaboration analysis the CoCa tool of Pol et al. [POL2007] could be a possibility to track IRP SPP workshops in terms of content, activities and practices. In identifying how participants in IRP SPP workshops collaborate, practices can be improved thanks to knowledge, experience and skills and based on this understanding.

7.4 Detailed IRP SPP process design

Every cycle has individual activities that lead to success in the set main cycles described in Chapter 7.3.1. In the following chapter, detailed sub-phases (input, divergence, convergence and output) of every cycle are presented through activities and related results. An overview image for every cycle at the end of each chapter details the sequence of core activities and core knowledge in the respective cycles. It is and shall not be fixed what tools/techniques have to be used when carrying out the cycle activities described in the following, however tools have to be chosen that enable effectiveness and efficiency through flexibility, agility and nimbleness [LUT2014].

7.4.1 Priority topics

The target of the first cycle of priority topics is to process relevant trends in a way that topics can be derived and focal points can be identified. Relevant trends are indicators in a certain direction in a given “search room” that have lasting effects on the future development of a company, respectively the production. The search room includes factors that are external (social/cultural environment, capital market, competitors, standards, suppliers, partners, workforce, state, politics, laws and universities) and internal (up and downstream indirect areas, such as product development, procurement and sales). See Figure 3-2.

Relevant topics for IRP SPP are determined by researching the amount, certitude and completeness of information needed. In the following the four sub-phases are described.

(1.1) Input:

The target is to determine information relevant to IRP SPP for the workshop series in divergent thinking after IRP SPP has begun. Thus, the SPP environment is monitored with the help of corporate managers who ensure that all relevant trends are considered. Internal and external trends along with

relevant strategies and directives from production, product development and procurement contribute the main input. The participants of the core team provide important information on production, product development and procurement. Through a systematic procedure, input is selected, prioritized and illustratively and descriptively prepared. Sometimes relevant knowledge is already in the company, but often it is not made transparent. To make existing knowledge transparent and visible, internal sources can be tapped regularly. This can be accomplished by interviewing key members/divisions concerning their opinions on relevant trends to get a feeling as to what topics are internally viewed as more influencing than others. Nevertheless, the search effort for relevant input must be reduced to a practical cost-benefit ratio, because of limited capacities. The huge range of topics in the world of trends must be reduced to a manageable number of important topics for the specific production process.

(1.2) Divergent thinking:

A core element of the second step is to creatively consider the direct and/or indirect impact of trends on the production. Experts from diverse hierarchical levels and different domains such as procurement, product development and production work together in moderated creative sessions to analyze input relevant to production in the context of SPP. These considerations lead to ideas related to trend impacts. Depending on the subject under investigation, selected creativity techniques shall be used for facilitating ideation by out-of-the-box thinking. Such techniques include the Scenario Technique, Six Thinking Hats, Provocation, Do Nothing, Force Field, etc. The different viewpoints of production, product development and procurement enrich the ideation through the perspectives used. Controlling can be an interesting additional viewpoint. But ideation needs to be appropriately guided in a way that participants are not overstrained but have a clear focus on ideation (see workshop references in Chapter 7.3.1). In generating ideas, it becomes clear which trends truly influence the individual production process significantly and in what way with a very wide view and on a relatively high strategic level. But ideas have to be consolidated in plenum that everybody has the same understanding them. Stakeholders acquire knowledge on what trends mean for the specific production process and considering the different viewpoints. After this step participants benefit from the diverse knowledge exchange coming from different areas and the beginning of a relationship network. In the next running of the cycle, more new stakeholders, e.g., controlling can be added when regarded as necessary. With the first running of the cycle, a basis is created which can be built upon in the next running, increasing the cycle's self-sustainment. A prerequisite is structuring the various ideas through categories to process them further in the convergent phase of Cycle 1 with transparency of the connected topics (structure of the diverse topics).

(1.3) Convergence thinking:

The target is to determine priority topics in considering the overview of generated ideas in 1.2 along with prioritization of diverse topics. As in the previous step, consideration takes place on a high strategic level because management participation is mandatory. As mentioned in Chapter 7.3.3, the decision-making must be simple, collective, systematic and traceably documented. In addition, the prioritization of topics takes into consideration how aligned with strategy topics are and what initiatives already exist that contribute to aspects of priority topics. No topic will be rejected but rather documented because it may gain further importance later. To get a comprehensive overview of topics, priority topics must be structured through categories and illustrated with detail levels and dependencies to other topics. Stakeholders and management are aware of priority topics, respectively their interdependencies with other topics, and know their complexities, especially what topics influence the individual production in what order of priority. In a first iteration of this cycle step, the overall scope will be defined whereas the further iterations will focus on refining previous ideas. New ideas can be integrated into the existing stock of ideas at any time. But the actions in both cases will differ. The updating of priority topics in terms of new strategy directives and gaps is more important after the first running. The determination of priority topics is very important because the rest of the process is based on them. If the company views a topic to be innovative it will be investigated further.

(1.4) Output:

To prepare the next cycle the chosen priority topics have to be analyzed. In generating key questions, the topic is rendered tangible and reveals dimensions and interdependencies. It must be clear what aspects have to be considered when examining this subject holistically. In this way stakeholders understand the chosen topic in all dimensions/interdependencies.

A further important activity in this follow-up step is the marketing of ranked priority topics. Already involved and further necessary employees in production, product development and procurement must be informed regularly about confirmed priority topics. Existing regular meetings can serve as the platform for this information. Furthermore, the core team members can disseminate information in their areas. The regularity of dissemination of information increases the credibility of IRP SPP proceeding within and outside of production and encourages utilization of results. Through a good quality of information, marketing stakeholders become aware of the increasing benefits of interdisciplinary and connected work and thus create a culture of partnering. Figure 7-10 illustrates the main activities and main results of Cycle 1.

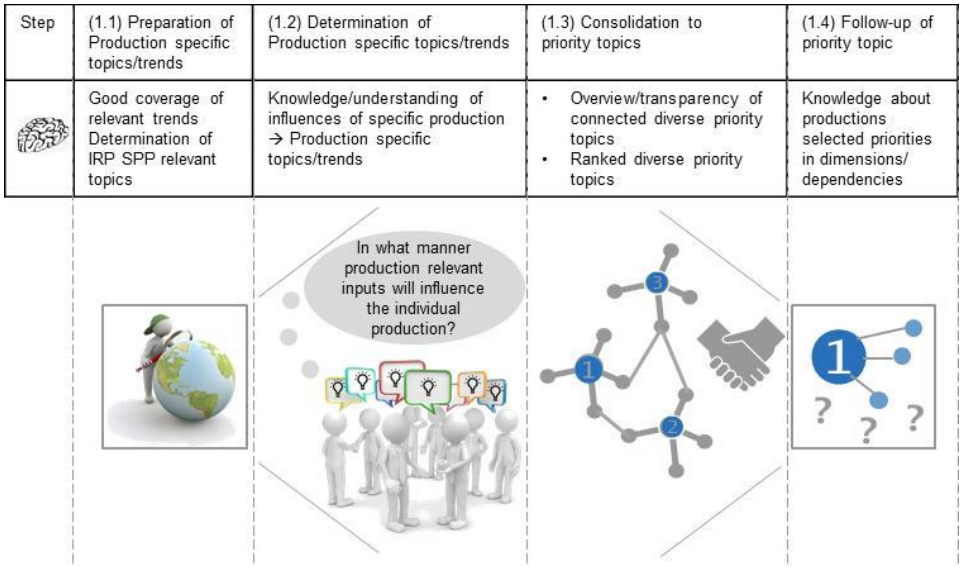

Figure 7-10: Cycle 1 activities and main results

7.4.2 Fields of actions

The target of the second cycle is to understand the chosen priority topics with associated challenges in the specific industrial context with given dependencies. If dimensions of subjects are clear the topic can be tackled systematically. Action fields which address the right issues are identified. In the following, the four sub-phases are described:

(2.1) Input

To be prepared for analysis, the chosen priority topic must be pre-analyzed in a broad investigation that reveals its dimensions. According to the chosen topic, analysis must be adapted. To get a common understanding of the topic, key questions must be answered. Furthermore, dimensions and dependencies among them must be analyzed to know which way to approach the topic. Through this in-depth analysis, it becomes clearer which participants to involve in the next creative sessions to get a holistic view. Existing initiatives/projects/processes are identified and considered. In addition, preset terms are selected to be defined collectively in the next step for a common understanding. Finally, the priority topic is reformulated, when required, to consider the progress of findings and to focus on a certain aspect/dimension. The appropriate formulation of what aspects of a priority topic to be investigated is critical to making further processing successful.

(2.2) Divergent thinking:

Creative sessions are central to this step. Depending on scope and capacities several or just one workshop must be planned. The following activities are described that must be done in the workshop/s.

Because topics are complex and terms sometimes ambiguous, a general terms list must be developed to clarify definitions in the creative sessions. This finalized vocabulary, which is seamlessly understood, avoids misinterpretations [KOE2001].

In the structured and guided analysis of the chosen aspect of a priority topic, a target scenario ("to-be" scenario) of the situation under review is detailed first. The picture is described precisely in target requirements formulated in whole sentences. To not forget important aspects, the ideation of target requirements is guided and enriched by given dimensions, e.g., management, processes employees, topology, function, product, etc. Because priority topics are very diverse, it is not possible to always use the same dimensions. Depending on the topic, only certain dimensions make sense (See example in case study Chapter 8.3.3). If participants find an important feature but are unclear on how to formulate it in a statement, it can be expressed in a question. After the ideation for target requirements, the groups present their results in plenum. A shared perception is built in a joint discussion.

After describing the actual situation ("as-is" scenario), the requirements are then evaluated collectively in terms of current fulfillment. The degree of fulfillment is indicated on suitable rating scales. It is important that the assessments take place with consensus and all confirm the assessment. This assessment is a very time-consuming step, but must be done in the same workshop where requirements were refined. If not, new participants should be informed in a further workshop on how requirements were built, but this is time-consuming, too. The range of assessment must be selected carefully. If a requirement is judged not to have been fulfilled very well, the employees affected by it may feel at fault and seek to change the assessment. Moderate assessment standards should diminish that issue. In this way stakeholders would accept the evaluation of the current situation and stand behind the decision-making, even if the current situation differs markedly from the target situation.

The requirements with the biggest deviations between "as-is" and "to-be" scenarios are further analyzed and described in guided categories. Discovered building sites are then justified with causes.

Finally, a consolidation (and if possible clustering) of causes is made in plenum to create a common understanding of the causes. These causes represent the object of observation in the next step.

Table 7-1 gives an overview of the convergent step 2.2 from target requirements over the evaluation in terms of current fulfillment and reasons of deviations (= causes). It is recommended to work with Excel as tables can be prepared in advance and it is a known tool in industry.

	Requirement ("to-be" scenario)	Evaluation	Causes: Compe-tencies	Causes: Organi-zation	Causes: Process	Causes: Techniques	Causes: Others	Notes
Management								
	xxx	1	yy					
	xxx	0		yy		yy		
	…	…	yy					
Process								
	xxx	1		yy				
	xxx	0						
	…	…						
Employees								
	xxx	1				yy		
		0	yy					
		…						

Table 7-1: Example of sequence of the divergence step in Cycle 2

(2.3) Convergent thinking:

In this step determined causes in 2.2 are examined. If a holistic further proceeding is needed, the descriptions of causes are reformulated, targeted and logically summarized to provide a deeper understanding. The wording must comprise the refined state of knowledge, respectively, work progress. In creativity sessions causes of the biggest building sites are examined to acquire a deeper understanding of causes in terms of scope and dimensions. Based on this examination, fields of action are generated in ideation. The fields of action must be described in as much detail as possible. A holistic further proceeding of causes is ensured and enabled, because stakeholders know the starting points to approaching causes/building sites.

(2.4) Output:

The follow-up of this cycle includes a broad investigation of fields of action. The topics are expanded in aspects and dimensions to acquire a deeper understanding of fields of action. Either in creative sessions or in the core team, fields of action are ranked in as to probability of success, cost-benefit ratio and relevance. More criteria can be added if necessary. What is important is that decision-makers have the right viewpoints and are able to estimate the activities to do when approaching a field of action. Figure 7-11 illustrates the main activities and main results of Cycle 2.

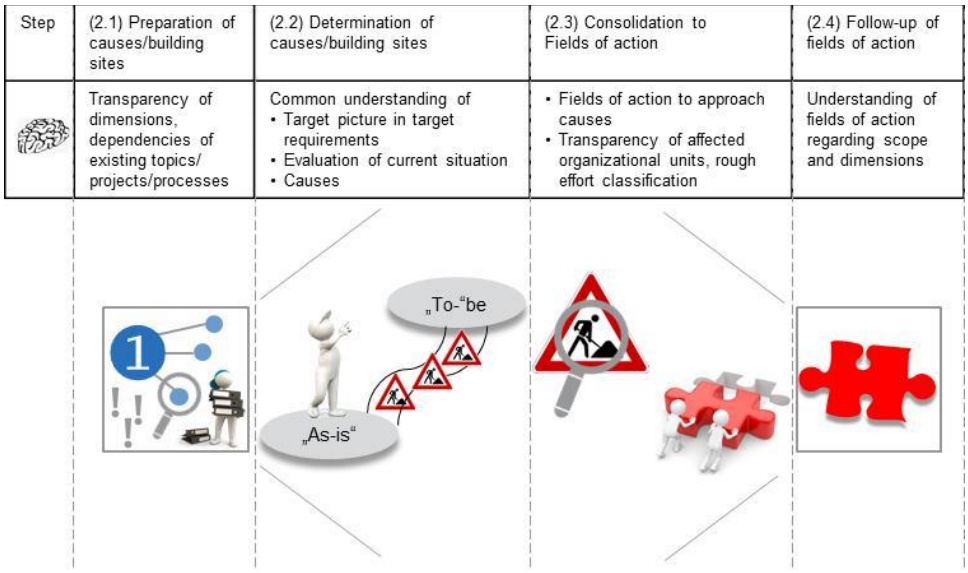

Figure 7-11: Cycle 2 activities and main results

7.4.3 Concrete actions

The target of this cycle is to identify and refine approaches, so that concrete actions could be implemented at any time. Concrete actions contribute to priority topics and are visualized in the final production roadmap. In the following the four sub-phases are described.

(3.1) Input:

In this step, the preparation for the divergent thinking step 3.2 consists of a fine-tuning of fields of action. Each field of action is holistically described through the following points:

- Affected organizational units: Interdependencies with other topics/projects/processes; Integration in (strategic) initiatives/projects and their networks.
- Rough classification; Rough temporal positioning.
- Key actors (internal and external people, sites, areas, departments, roles, etc.).

In the fine-tuning, ideation in the next step is then based on a clear understanding of what scope and which processes/projects to consider when approaching a certain dimension of a field of action. Fields of action must be ranked appropriately to define only concrete actions for those fields of action

with the most potential in the next step. Prioritizing of dimensions of fields of action should be made by experts affected by the subjects under evaluation. They need to consider the context, availability of the requisite resources, relevant existing processes/projects that counteract or contribute to concrete action and probability of success.

(3.2) Divergent thinking:

In this step, ideation is made to find concrete actions that address action fields. Concrete actions have a long-term aspect and are traceable to an action field, respectively, a priority topic. The concrete actions with the most potential are then formulated in-depth into "innovation project briefs". The rough structure of an idea's description can be extended but should include:

- problem definition,
- target,
- projected costs,
- procedure (time frame, starting points),
- chances/risks,
- key actors,
- other.

In these briefs, ideas about concrete actions are described in such detail that they could be implemented at any time. In addition, the file description serves as a documentation object that can be updated as to the ongoing status of activities that are done or are planned as the project runs.

At this low concretization level, ideation sessions include affected experts with specific knowledge of the subject. The formulation of innovation project briefs is a very time-consuming activity, which is why it is recommended to do one creative session for one concrete action. In this way participants who are well-suited to the topic can be chosen.

(3.3) Convergent thinking:

In this step, formulated concrete actions and existing relevant initiatives are evaluated as to their structure and appropriateness. In the evaluation of all current and new topics, the company's existing initiatives must be documented to a comparable degree and at the same strategic level as concrete actions generated in IRP SPP. The target is not to create a simple project plan documentation of all initiatives in production, but to document completely the state of the art of all initiatives (ongoing, planned, required) that contribute to topics in innovation project briefs. Several initiatives can contribute to one innovation project brief. In this way, it becomes clear what innovation project briefs have a greater need for action than others. The more concrete actions are identified, the more complete innovation project briefs become. The evaluation must be done by experts capable of comparing topics on a strategic level and with in-depth knowledge. Companies must choose adequate criteria for them,

because at this concretization level evaluation is very specific and context-dependent as to what innovation project briefs are the most important (See an example in the case study Chapter 8.3.4). In this step, innovation project briefs consisting of production contributions to priority topics are the output.

(3.4) Output:

This last follow-up step consists of the positioning of innovation project briefs in the production roadmap. The visualization of roadmaps can differ highly as mentioned in 4.2. There is no perfect roadmap; but it is important that the roadmap consist of a time frame and an axle of relevance. Furthermore, innovation project briefs in the roadmap must show clear additional information about the topic, e.g., group relevance or ongoing/future topics. In addition, it must be possible to click within an innovation project brief to access all relevant information (existing initiatives that contribute to priority topics with associated trends, connections/dependencies to other topics, etc.). The usefulness of an IRP SPP becomes apparent through a high-quality roadmap that shows what focal points in innovation project briefs must be approached through recommended, generated concrete actions.

Although it is not part of the content of the IRP SPP to compel the implementation of the generated concrete actions, the implementation of projects positioned in the production roadmap can be monitored. A yearly update must be done to assure the actuality of existing projects briefs, or to creation new briefs. Because IRP SPP lacks implementation power, it is recommended that those responsible for resource funding are involved in the IRP SPP, so they can see the concretization and prioritization methods and understand why evaluated innovation project briefs need funding for proposed actions to be implemented.

The production roadmap functions as a marketing tool for distributing relevant information to stakeholders and funders on the results of the IRP SPP. A prerequisite is a communication strategy that encourages a utilization of clear roadmap results that can be disseminated to “customer groups”. The information flow between production and dependent departments within/outside production can be improved by yearly updates of production roadmap results. In this way, stakeholders

- know the pathway from trends to projects due to transparency,
- are aware of the effort that goes into building a high-quality and thorough roadmap,
- better understand and overcome barriers to development and transfer of critical technologies,

- especially government/management become more responsive to the needs of a production roadmap.

Figure 7-12 illustrates the main activities and main results of Cycle 3.

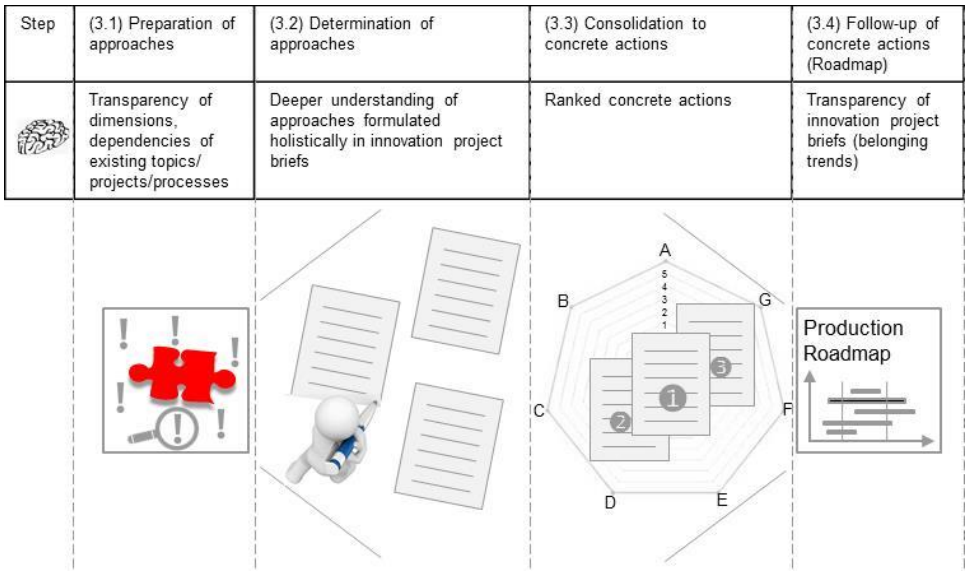

Figure 7-12: Cycle 3 activities and main results

7.5 Measurements approach

To facilitate the management and continuous improvement of the IRP SPP in practice, we devised an efficient and effective measurement approach to capture global process performance as well as performance per phase. Due to the process's highly dynamic and creative nature, the classical straightforward measurement approaches applied to well-structured static business processes were deemed to be inappropriate.

To look deeper into this, we performed a literature review whose main insights have been summarized in 7.5.1. Complementing them with our own ideas, we will propose the fundamentals of a measurement approach for the IRP SPP in 7.5.2. We will apply and validate this approach in the case study in Chapter 0.

7.5.1 Literature review: measuring the roadmap

The problem is that due to the complex product of a roadmap, it is never finished, so success is very difficult to measure. However, if things are new,

evolving and dynamic then what to measure and how to measure them are the challenges [KIR2013]. Everything that cannot be measured attracts little attention in everyday business [HOR1999]. The target of measuring is always to find out the level of quality in which a process works. Approaches from process controlling look at the measurement of effectiveness and efficiency regarding how well a process achieves the target [GUS2013]. Innovation management performance needs to be measured multi-dimensionally, by process, ease of implementation and use [DEW2014]. Only a few such approaches of measurement and criteria exist, thus experience values and possible potentials are often measured. But the right criteria are necessary to measure [KAP2001]. Vatananan et al. [VAT2012] proposes an evaluation model that is based on changes in key drivers and their collective effect on a roadmap to determine the current state of a roadmap. But this approach is complex and not applicable.

Kappel proposes criteria that consider the areas of influences of a roadmap to understand, persuade and synchronize: accuracy or clarity, aligned priorities and decisions and ongoing coordination [KAP2000].

In KPI literature, Sari [SAR2015] proposes useful guidance to determine KPIs through the following questions:

- Who are the key stakeholders and their wants and needs?
- What strategies do we need to deliver value to stakeholders?
- What processes do we require to deliver these strategies?
- What capabilities do we need to operate and enhance these processes?
- What contribution do we require from our stakeholders if we are to maintain and develop these capabilities?

To determine KPIs Sari [SAR2015] focuses primarily on the understanding of process objectives and stakeholder satisfaction, respective to each stakeholder. KPIs should be understood as a form of communication. Pointing out the specific wants and needs of each stakeholder is not an easy task when considering multiple stakeholders' requirements and does not always provide sufficient proof that a process works. Therefore, it is also necessary to identify the KPIs that represent the organizational objectives [SAR2015].

Chiesa et al. [CHI2009] offers a generic model that shows which elements are needed to effectively use KPIs. These fundamental constitutive elements of a performance measurement system measure and evaluate collaborative R&D. As pictured in Figure 7-13, indicators (quantitative and qualitative) are identified in considering objectives, different perspectives of performance dimensions, and control objects in a structured measurement process [CHI2009].

Industry Canada [IND2007] offers a measurement approach that is based on transparent results being achieved through activities in TRMs. For each result, indicators are proposed and listed that qualitatively or quantitatively measure this special result. TRM consists at Industry Canada of three equally important steps to developing the roadmap: first, to embrace the TRM concept; second, to implement the TRM through defined and initiated projects that are monitored and managed; and finally, to plan for subsequent iterations of the TRM to evolve and become self-sustaining. That shows that the roadmap is manifested through concrete projects and systematic updates. A key element in Industry Canada's approach is that activities, in-/output, and results of TRM are made transparent. However, the results as output from TRM are expected to be different in each company. So, the evaluation of results from any one TRM may also differ from others. That means results cannot simply be transferred onto another roadmap, but must be refined specifically for each roadmap. Industry Canada presents an approach for evaluating TRM results as a guideline, not a prescriptive recipe. But a series of common yardsticks by which the performance of TRMs can be determined is provided.

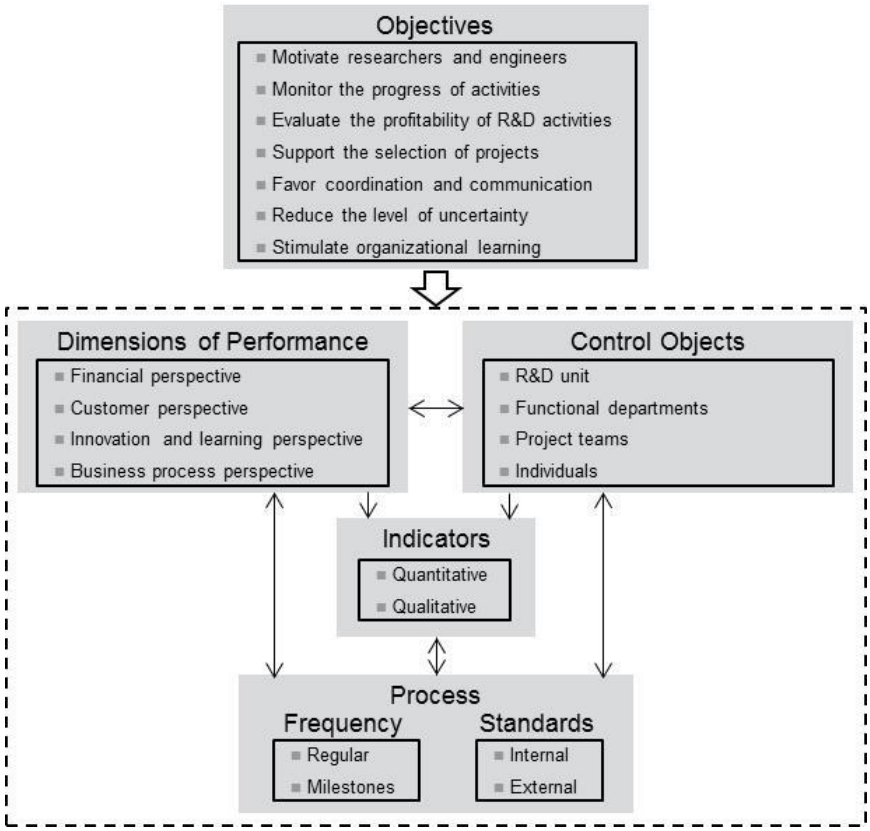

Figure 7-13: Performance measurement system for R&D [CHI2009]

7.5.2 Measurement approach

Industry and literature shows that TRM is very particular in terms of scope and content depending on industry and company. Therefore, the measurement approach for IRP SPP must be constructed in a generic way without elements that are too highly specific for a particular domain and/or environment.

Two possible ways have been considered:

1. Top-down approach: With the viewpoint of the management, measurement indicators are defined to provide management target values over time (first year, second year, etc.), measuring effectiveness and efficiency of the IRP SPP.
2. Bottom-up approach: Measurement indicators are defined to provide future IRP users a choice of feasible measurement indicators that measure the functioning of the process. The aim is to identify indicators that can be applied and are not too complex or costly.

Within the scope of this thesis, the bottom-up approach was deemed the most possible to develop and is presented in the following.

Assuming implemented process requirements (see 7.3), along with associated activities and results from IRP SPP cycles (see 7.4), reflect the functioning of the process, measurement indicators are related to the requirements. Results in the IRP SPP cycles are the outcome of successfully implemented process requirements and the functioning of the IRP SPP. This is why it is not sufficient to only propose measurement indicators; one also has to explain the method for determining indicators, clarifying activities and results in the IRP SPP cycles.

In Figure 7-14 the bottom-up measurement approach for IRP SPP with its three necessary process steps is presented.

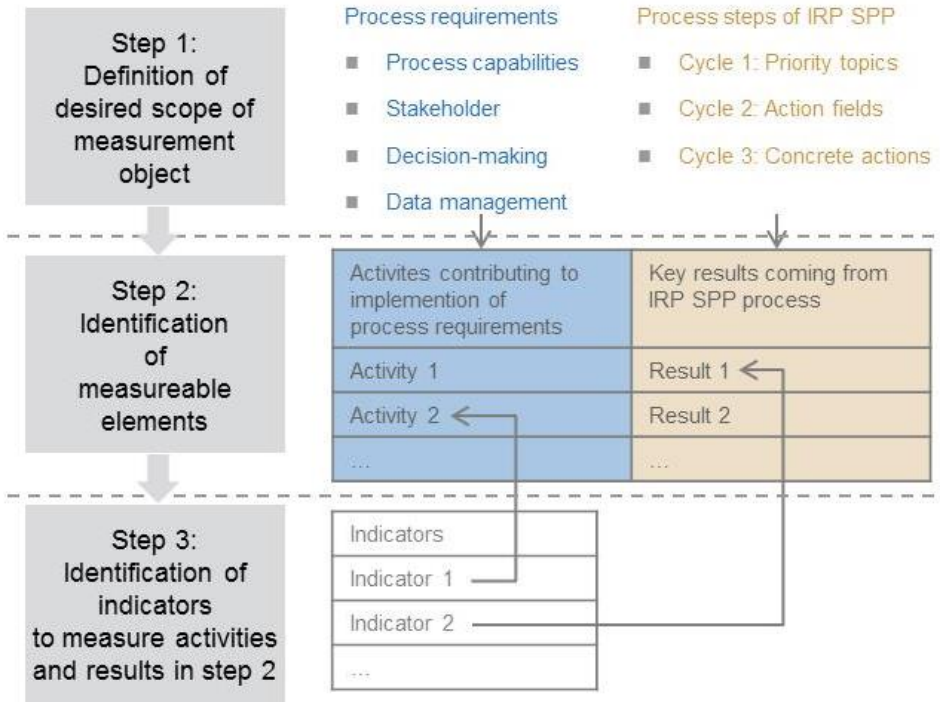

Figure 7-14: Generic measurement approach for IRP SPP

Step 1 consists of defining the scope of a measurement object in terms of process requirement categories (see Chapter 5.2) and process steps (see Chapters 7.3 and 7.4). For example, it is possible to measure just data management aspects in Cycle 3 of an IRP SPP or to evaluate only decision-making aspects in all SPP steps.

Step 2 clarifies what concrete activities contribute to implementing process requirements and what key results arise in the IRP SPP process steps.

Step 3 identifies indicators that measure the operation of identified activities and results in Step 2. Indicators work over time as comparison values, such as a trend profile that identifies the performance over a period (per process run, per year, etc.). With that performance value, continuous improvement can take place based on the value trend development, and management decisions are made based upon observations over an extended period. Indicators are oriented to process requirements and can be clustered in the same categories, namely process capabilities, stakeholders, decision-making and data management. Quantitative and qualitative indicators consider organization and the progress of content.

In the following Table 7-2 the indicators are presented:

Process capabilities KPIs	
Workshops	Number/relative "importance" of members involved in workshops and core team
	Extent of work effort: Planning time for agenda, workshop presentations, minutes, reporting (methods, practices for transferring information)
	Number of ideas (e.g., approaches/projects formally produced, established, developed, implemented)
	Number of ideas with social networking (needs interdisciplinary knowledge inter-divisional, in the responsibility of more than one expert group → degree of novelty)
	Number of ideas that have become more mature during the workshop
	Workshop efficiency: Ratio of refined results (number of ideas, concrete actions, logical paths from trends to concrete actions) to resources needed (time, person days)
	How suitable were creative techniques for the workshop
	Workshop effectiveness: Aim achievement in %
Communication	Number of stakeholders involved in at least one IRP SPP workshop
	Number of stakeholders in attendance at IRP SPP presentations
	Volume/number of discussions with potential IRP SPP users
	Number of requested IRP SPP materials/presentations/documents by production and others
	Extent of announcement of IRP SPP document within the company, between departments
	Number of references to TRM results in communications
Organizational embedding	Number of departments and segments affected by IRP SPP output
	Influence on other departments through IRP SPP results
	Changes in production strategy, directions through IRP SPP output
	Frequency of active reuse of IRP SPP output in meetings at all strategic levels (e.g., strategic meetings at top management such as BU Planning)

Open view of innovation	Strength of linkage between IRP SPP topics
	Linkage of IRP SPP topics to strategy topics
	Number of priority topics' dimensions affected through new generated ideas in the whole IRP SPP
	Level of involvement of participants with relevant perspectives (dimensions of chosen topic must be addressed) along the process though consultations and active participation
Rolling process	Scope of subsequent TRM iterations, i.e., time, capacity, methods, tools
	Evidence of accomplishments from previous iterations – may be just anecdotes
	Run through of all three cycles of IRP SPP in one year
	Progress of activities contributing to priority topics/concrete actions
Stakeholder KPIs	
Management	Level of involvement of senior management team: Time involved with IRP SPP workshops and core team
	Number of actions, communications, interventions initiated by IRP SPP team with management
Acceptance	Overall positive reception of IRP SPP by participants
	Recognition that results are from a TRM initiative
	Awards for performance of participants
	Participation of key stakeholders in core team and workshops (especially production, product development, procurement)
	Support of stakeholders for IRP SPP topic: Relevance, involvement, contribution
	Increased commitment of funding to IRP SPP by management and stakeholders' management (i.e., number of person days, number/level of resources allocated to IRP SPP projects)
Networking	Enhanced mutually beneficial cooperation: number of discussions between departments, established formal or informal alliances
	Number of new participants in the IRP SPP
	Level of involvement of key members

Decision-making KPIs	
Decision-making	Changes/improvements to relevant selection criteria
	Duration of aligned prioritization decisions
	Concrete indicators for prioritization
Data management KPIs	
Cover-age	Database that documents all topics to consider all trends, avoid blind spots and lose no topic
Traceability	Traceability of idea to trend or priority topic (evidence of linkage between selection criteria, building sites, fields of action, approaches)
	Documentation of participants, minutes, workshop presentations, output, etc.
	Number of participants with successful access to database (containing TRM results)
	Documentation of the development of topics over the course of a year: maturation of topics (how often and deeply topics are treated)
	Clarity of IRP SPP results for users
	Good quality of IRP SPP results

Table 7-2: Measurement indicators for IRP SPP

Because the measurement of IRP SPP is very dependent on its application in the specific production context, proposed measurement indicators can offer an orientation for indicators, but are not complete. In the case study (see Chapter 0) some selected indicators were verified to prove their plausibility.

Part III:

Case Study

8 Implementation of the IRP SPP at ZF

8.1 Context

The global objective of the case study was to validate the presented IRP SPP in the corporate context of the automotive supplier ZF through its implementation in the company's existing process landscape. The pilot specification required accomplishing one complete iteration of the IRP SPP in one division in the time frame of one year. The requirement was to start with at least two megatrends and process them through the end of the IRP SPP, leading to concrete actions for projects to be positioned in the innovation roadmap.

In terms of stakeholder availability, we were limited to holding planning workshops no more frequently than every two months. The core team acted as the process steering committee and met every month.

With respect to the IRP SPP process requirements, the following items were specifically highlighted:

- Process capabilities: A feasible process that would not be too theoretical, applicable in all BUs and could begin at any point was required. Furthermore, regular, frequent sessions were envisioned to keep the collaborative network alive. The integration of the IRP SPP in existing processes was of major importance to the company, so that it could be incorporated in future ongoing processes. Because ZF is already familiar with technology development, a good diversity of topics in terms of openness regarding new ideas in every step was required.
- Stakeholders: Different stakeholder perspectives were to be integrated through diversity in participants. This required guidance, especially in the creative sessions, to achieve autonomous networking of all involved throughout the process.
- Decision-making: ZF required simple and comprehensive decision gates.
- Data management: It was required to model the identified topic network in multiple levels of detail to enable networking between the topics (ideas). In addition, data integrity was required to ensure completeness and avoid the loss of any ideas along the way and beyond the process iteration. The most

important point in data management was to ensure the bidirectional traceability from trends, priority topics to concrete actions in the roadmap to provide a complete record of ideas and decisions that led from trends to particular actions, as well as to justify decisions made in the roadmap (new projects, re-positioning of already planned projects in the roadmap, etc.).

- Moreover, ZF required obtaining measurement indicators to measure the functioning of the process (see Chapter 7.5).

To put the pilot specifications into practice and apply the IRP SPP at ZF, the context of the organization of ZF and relevant existing processes and gaps were considered and are presented in Chapter 8.2. In Chapter 0 detailed implemented process steps are presented. To satisfy the additional requirement of measurement, Chapter 0 specifies selected measurement indicators applied to the pilot at ZF. Finally, in Chapter 8.5, the IRP SPP was validated through a check of process requirements, recommendations from the experience obtained in the case study and the added value for ZF.

8.2 Initial situation

To apply the IRP SPP at ZF, the specific context must be described. The department in which the IRP SPP was to be implemented is presented with its specifics in Chapter 8.2.1. In addition, the IRP SPP must, as required, consider existing ZF processes. Therefore, the relevant existing processes and gaps in the current situation at ZF are presented in Chapter 8.2.2 to show the current contribution to TRM at ZF.

8.2.1 Organizational scope

With 230 production companies in 40 countries, ZF is one of the global leaders in driveline and chassis technology. In fact, it is among the top 10 largest automotive suppliers worldwide with revenue of more than 35.2 billion euros and 136,820 employees in 2016. Through the acquisition of the U.S. company TRW in 2015, ZF Friedrichshafen AG almost doubled in size. [ZF2016a]. This thesis was located in the division of Commercial Vehicle Technology, denoted Div. T, with total sales of 2.960 million euros in 2016 and 11,594 employees worldwide in 22 locations in 14 countries. The product portfolio extends from chassis and powertrain modules, through damper technology for truck and van driveline technology to axle and transmission systems for buses and coaches [ZF 2016b]. The corporate organization is characterized by production operating separately from the design department.

The thesis was initiated and sponsored by the department of technology development, which is part of production management and engineering which

includes innovation management and knowledge exchange. The department perceives itself as the operational and strategic partner of the production, product development and purchasing departments of all division locations. Thanks to the broad approach of innovation management within production and together with internal customers, key aspects of production technology are jointly defined. Ideas and innovations from innovation processes are picked up, developed and implemented via Advanced Production Engineering Projects. The know-how exchange process ensures that the knowledge gained in the course of the aforementioned processes is made available, globally and in various languages, to partners and customers within the division.

8.2.2 Existing processes and gaps

In the following, existing processes contributing to IRP SPP are identified. In addition, existing gaps are described. Finally, guidance is given on how existing elements can be used in the IRP SPP to complete the process regarding actions to be taken.

Existing processes: Ideas and relevant information are described and archived in detailed technology specification sheets. There is a systematic evaluation system for technology specifications. An extensive Excel-based evaluation method suited for use at ZF to evaluate and select strategically important technology projects was refined in 2007 in collaboration with the University of St. Gallen, Switzerland. Technology specifications are listed in the production roadmap. The production roadmap and technology specifications are updated once a year and act as strategic tools to model future projects and make recommendations for action. The production roadmap of Div. T is retained at the corporate offices of production where all production roadmaps are consolidated into main topics. These main topics are assimilated into the corporate innovation process in which the product roadmaps give input for production. A procurement roadmap was built for three years, but with no points of contact with the production roadmap, so far.

Gaps: Concrete actions contributing to main production points were identified, more accidentally than systematically, and were based on observations of production problems. In addition, ideas were identified in an unsystematic manner through infrequently held workshops, wherein topics and scope of the workshops were uncertain as well as how to proceed with identified ideas. There was no systematic way of considering trends, analyzing them and understanding challenges associated with the trends at ZF. Even if employees considered aspects that were not purely technical—such as organization, support and human resources—in their daily business, the topics in technology specifications were not systematically opened to discussion of these other aspects and were very technical, if they were brought up. Technology

specifications were formulated at different levels of concretization, scope and character (sometimes it was just a simple project list). Therefore, a comparison among specifications was not possible. Input regarding trend management did not take place systematically. The evaluation tool was tested only once, but was not used in practice because of the high evaluation effort—too much technology specification not adequately formulated and lacking new ideas. Therefore, projects were decided mostly based on the urgency of production problems or the judgment of one particular expert.

In summary, ZF already had elements contributing to IRP SPP Cycle 3. In particular, the following were usable for the IRP SPP:

- The template of technology specification.
- Central data management to document and update technology specifications.
- The automatically generated production roadmap.
- The evaluation tool of technology specifications. At least, evaluation criteria if the evaluation step is too extensive.

But a systematic process that would result in technology specifications, especially all methodical steps in Cycle 1 and 2, were lacking completely.

8.3 Process implementation

Based on the reference process, see Figure 7-6, and planning requirements/restrictions, Figure 8-1 shows the actual implementation in the pilot phase. The general process (Figure 8-1) was adapted to the workshops conducted at ZF in the year-long pilot phase. The blue boxes describe the main activities in the workshops that link to the detailed process steps and indicate what process step the workshop belonged. In addition, the process numbers are specified in the detailed process step description. In the beginning, it was decided that in the pilot phase at least two megatrends were to be worked with to the end. But as highlighted in the picture, the scope was adjusted according to the given capacities. This was because without some limitation there was no guarantee that final actions could be funded as the scope was too broad and costs would be too high. The green points illustrate the decision-making points where pilot scope was adjusted. Thus, the target to run through IRP with at least two megatrends was not met, but the more important target to run a complete cycle was.

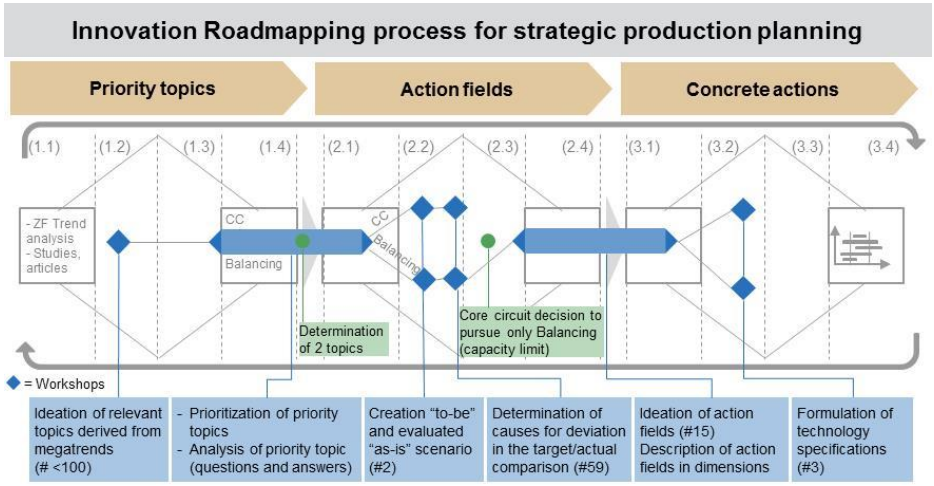

Figure 8-1: Scope of case study workshops

Chapter 8.3.1 goes into more depth on the overview of the pilot phase. The two terms "CC" and "Balancing" around the second workshop are the chosen topics. The topics, as well as the input box of the first cycle, are described in Chapter 8.3.2. The detailed process steps are presented in the Chapters 8.3.2, 8.3.3 and 8.3.4, each of which ends with a figure that summarizes the main activities with actual excerpts from the pilot.

8.3.1 Overview of pilot implementation

An initial key effort was to integrate stakeholders in production, development and procurement in this pilot as participants in the core team and the creative sessions. A core team was established which was part of both the steering committee and the ideation teams. The team size varied between seven and nine, depending on the experts' availabilities and the roles and expertise required for the objectives of each session. Influential representatives of the three areas—production, product development and procurement—were part of this core team, which was a significant change with respect to existing practices in the organization. The production experts were in the leading position, since the entire initiative was driven by them. Production sought to introduce a sustainable, systematic strategic planning process, starting from megatrends and ending in concrete project ideas placed in the production technology roadmap. A major requirement for the result was that it should reflect the holistic, integrated view of the three areas involved in the production planning, leveraging the role of modern production technology as a driver for innovation both of products, processes and the company's global organizations, including suppliers. Moderated ideation sessions with integrated design character were held about every five weeks over one year in a way that the three process

elements were covered exactly once over this time period in nine workshops. 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 carefully prepared 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 obtained in each session were consolidated and systematically documented. During each session, tool support was deliberately kept basic to maximize 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 were 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 to facilitate the application of integrated design approaches to ideation for planning purposes.

8.3.2 First cycle: Priority topics

(1.1) In the first step of IRP SPP in Cycle 1, a huge amount of data provided input, which 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. In addition, current relevant research papers and market studies for the commercial vehicle/truck manufacturers industry provided input. The 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 invented terms:

1. Glocalization of products/production sites (target conflict between globalization and localization):
    - Globalization with a strong need to adapt products and services to local markets' requirements and characteristics.
    - Potential for unprecedented growth in BRIC countries.
2. Hybridization of technologies and materials (combination of several technologies in the products):
    - Hybridization of several new (product and production system) technologies that take a long time to establish (e.g., light materials and electrification).
    - Hybridization of competencies, organizations, supply chains, product/service offers, business models.
3. Flexagility (being flexible and agile):

- Increasing number of product variants and increasing need for product personalization ("individualization").
- There is total uncertainty about winning technologies, processes and business models.
- Markets and technologies are increasingly volatile.
- The winners will be those with the highest level of responsiveness and flexibility, those that react rapidly and can master the increasing complexity in the industry and its dramatic transformation.

(1.2) In a next step, the experts worked together in small groups (two groups of three to five people each) to ideate about topics they consider particularly relevant for the selected trends, as well as for organization and cost (constraints imposed by steering team). In the introduction, the participants were given a short presentation to make them aware of the actual situation in terms of internal trends, megatrends impacting the revenues, costs and profitability for all stakeholders, globalization regarding market share, challenges and suitable winning strategies in the global commercial vehicle/truck manufacturers industry.

For the Glocalization trend, the Force Field creative technique was chosen and used in a one-day workshop. The target of the creative session was to find ideas to move away from the actual situation in the first scenario, "ZF disappears as production site", toward the second scenario, "ZF is the most important production site". Possibilities were to strengthen an existing positive force, to weaken an existing negative force or to develop a new strength. The generated ideas were clustered in the categories technology development/planning, education, organization in the broadest sense, cost and knowledge. But clustering took place with no firm boundaries; for example, the idea "Lead Factory" has a relationship to cluster technology, organization, knowledge and costs. This shows that revealed topics are complex and need to be considered in all dimensions and dependencies. Finally, the consolidation at the end revealed one more topic that was missed, namely the idea in risk management that all identified ideas were understood by all participants.

In one additional one-day workshop, the two trends Flexagility and Hybridization were processed through a creative session in which participants generated ideas questioning what chances and challenges ZF production is confronted with regarding the two trends. Two groups covered each trend. After ideation, groups traded trend subjects and reworked them based on the ideas generated by the first group. Here again, the consolidation at the end of the workshop established a common understanding of ideas and reasons why the ideas were written.

The groups in all workshops were composed of employees from production, procurement and product development. In addition, participants were mixed in groups regarding their hierarchical level to motivate, stimulate ideation and to assure that groups had similar levels of discussion.

About 130 ideas have been generated and consolidated in about 30 topics and six mutually linked clusters (processes, employees, competences, production network, external collaborations and infrastructure). An aim was to structure generated ideas in relation to organization and costs (implicit reference to technology), because technological knowledge in ZF production is usually quite mature and participants desired help in "non-technological" approaches.

After each workshop feedback was given, and in this early stage, product development had already begun to notice a surprisingly high number of legitimate production topics independent of product development.

(1.3) In the consolidation step the ideas were then ranked into priority topics. Each participant chose three idea clusters (second level of priority topics) and wrote priority 1 on a green card, priority 2 on a blue card, and priority 3 on a yellow card (See Figure 8-3 result from step 1.4). The selection was presented in plenum on a pin board and the order of prioritization was determined. Figure 8-2 illustrates the ZF-specific priority topics resulting from the first cycle. All priority topics are clustered in the categories processes, employees, capacities, infrastructure, networking and production network. Beyond the categories, priority topics were extended over two to three layers. For confidentiality reasons, not all layers but only the typical path of the chosen example in the category of production network is illustrated.

(1.4) In the priority follow-up step, selected cards were then clustered thematically. Those clusters containing the most green, respectively, blue cards were chosen for the output step to prepare topics for the next cycle. As the chosen clusters contained several topics, the Cycle 1 output step and the Cycle 2 input step merged into one workshop where 16 dimensions were analyzed, generating more than 100 questions to sharpen the issues and make them tangible. The dimensions were not related to action in the company, but served to expand the mindset of participants. Reflecting on the dimensions helped to capture overriding themes and categorize them afterwards. These dimensions covered subjects like knowledge management, decision culture, building up of competence centers (CC), balancing resources and capacities in the production network, reusability of machines and many more. Basic terms, like flexibility, were defined through the questions. Common to many dimensions was the subject of flexibility of both the organization and the manufacturing configuration and capacity (key challenges of Industry 4.0).

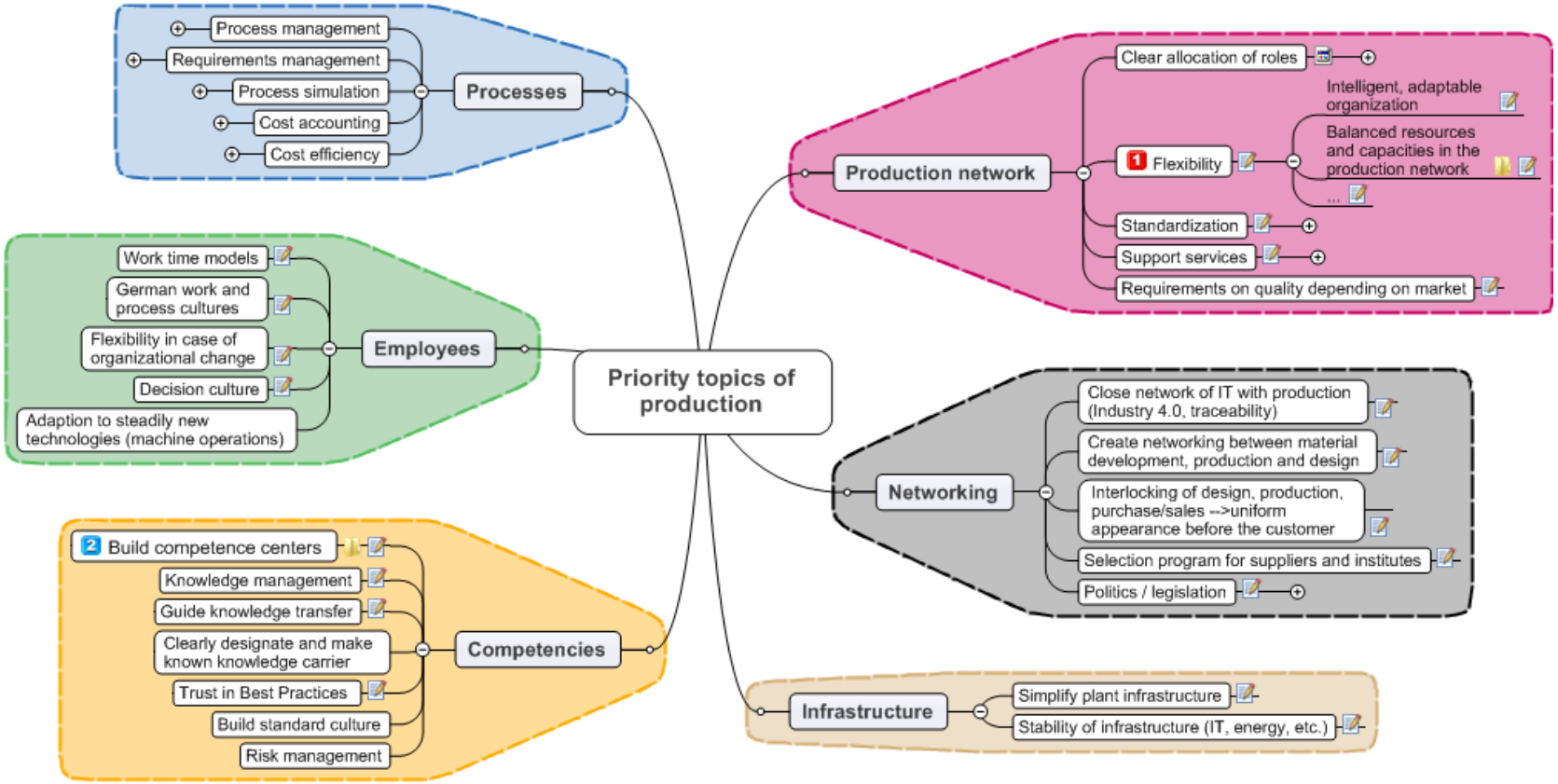

Figure 8-2: ZF-specific priority topics

All generated questions have been included in the priority topic reference model consisting of all identified clustered ideas derived from the trends Flexagility, Glocalization and Hybridization. In Figure 8-2 questions are linked through the writing pad with pin located after the priority topic names. Out of this model, lists of questions can automatically be generated for all ideas in ppt, doc, etc. Across the entire process, idea clusters can serve as input for Cycle 2 and 3, where associated questions function as starting points for ideation. Furthermore, relationships between idea clusters and single ideas can be visualized. Figure 8-3 illustrates the result chain of Cycle 1 beginning with relevant information in step 1.1, contained in relevant studies and ZF internally identified megatrends; in step 1.2 the priority topic ideas from creative sessions; in step 1.3 identified priority topics are categorized; and in step 1.4 the final decision through the chosen decision-making technique.

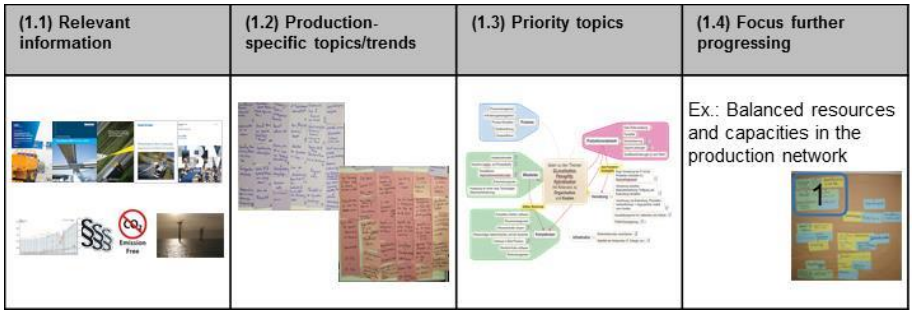

Figure 8-3: Result chain of Cycle 1 in ZF

8.3.3 Second cycle: Fields of action

(2.1) Because of limited capacities in the pilot project, only the following two priority topics were further progressed:

- Balanced resources and capacities in the production network.
- Build competence centers (named “CC” in Figure 8-1).

This choice was made based on the unanimous decision of the core team members.

The numbers (red 1 and blue 2) in Figure 8-2 highlight the prioritization. In addition, the little folders show if topics are being worked on with links to the findings. In this way, every topic can be processed with the full record of working progress. The first targeted topic was reformulated, so that all aspects would be considered: “the balancing of the complete (internal and external) production network” (named “Balancing” in Figure 8-1). The generated questions were answered in a workshop and necessary participants

for the next workshop, including preparation work for it, were determined. Participants reached consensus on the topic. Existing initiatives were identified and summarized.

In the following, only the topic "Balanced resources and capacities in the production network" is further illustrated, because it was the only topic processed through to the end of the IRP SPP. CC was rejected when it became clear that capacities were too low to completely process two topics.

(2.2) The next step was the creation of a target scenario with the concrete task to "characterize what, in your eyes, is a perfectly balanced production network at ZF with significant key properties". To describe the target scenario for each identified property and function, participants were asked to write one complete sentence in MSWord, including the following enriching dimensions:

- Topology: Locations (roles, types, etc.), networking, architecture, plant structure, etc.
- Products: Depth of production, car/truck, etc.
- Function: Processes (production, logistic), internal customer/supplier relation, models of cost allocation and value added, database, IT-infrastructure, etc.
- Management: Structure, instances, mechanisms, etc.
- Employees: Labor time model, competencies, culture and language, etc.
- Processes: Standardization / flexibility, agility (adaption periods), etc.

Important properties that could not be expressed clearly were formulated in questions to retain all relevant aspects.

Two groups were formed that worked 75 minutes on three dimensions. At the end, sentences were consolidated and discussed in a 30-minute presentation. In total 55 target scenario sentences were refined.

To describe the actual situation, identified requirements were evaluated on a scale of 0 to 3 to pinpoint deviations between the two scenarios (0 = does not apply at all, 1= rather not apply, 2 = rather apply, 3 = applies completely). Sometimes it took much effort to reach a common opinion on evaluation. For example, some people had to rate their own areas, presenting an apparent conflict of interest. When they rated them 0 or 1 they implied they had failed in some aspect. Since the requirement was to honestly rate their areas, they did so, but unwillingly. Therefore, it is important to not judge the low evaluation points too negatively.

The biggest deviations (evaluation of 0 and 1 at 25 sentences) were further progressed to identifying causes/challenges. As the biggest deviations emerged in the two clusters of organization (for balancing) and processes, participants made ideation in two groups, each in one cluster. The five dimensions of competence, organization, process, technique and others served as analysis guidelines for a systematic process. Causes/challenges were formulated as concisely and precisely as possible in a prepared Excel file pre-set with dimension columns. If no causes could be identified, questions were generated. In summary, 59 causes were identified, discussed and consolidated in the last hour. Figure 8-4 illustrates the simplified representation from target scenario sentences, over the "as-is" evaluation (evaluation), to causes, respectively building sites.

Balanced resources and capacities in the production network			
Di-mensions	Requirements	Eva-luation	Causes of deviations
Management			
	Central instance determines communication rules and mechanisms between locations.	1	Data and key figures are not sufficiently transparent.
			At under-utilization machanisms in network are not regulated centrally.
	Short-term balancing takes place via internal and external suppliers.	2	
	Long-term balancing takes place via central instance.	1	Roles of locations are not sufficiently defined. Locations are in competition.
	Breathing capacity and agility is high at all locations.	0	Some locations' operations are too slow and expensive.
	...		
Processes			
	Production network consists in internal and external suppliers.	1	Make and buy process requires a new way of cooperation.
	Quality criteria are crucial factors for the control of production processes.	3	
	Logistic processes between locations must be standardized.	1	Besides the technological aspects, are there requirements for standardiziation in logistics?
	...		
Employees			
	...		

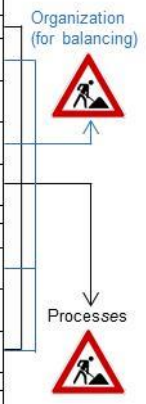

Figure 8-4: Simplified representation in Step 2.2 in ZF

(2.3) Because of the interconnection of topics, single causes/challenges were reflected on and logically summarized in the given dimensions to cause clusters. If needed, the description of causes was reformulated, so that wording reflect work progress. Since the dimensions technique revealed only one cause, the focus on organization and costs in Cycle 1 priority topics was validated. No causes (individual problems) were lost in the clustering, but were reassigned to the given clusters.

After a deep understanding of causes with the attendant challenges was acquired, it became important that the causes addressed should be processed consistently, respectively completely, and not only partly. Therefore, not all causes could be processed, but those in organization and process categories were chosen.

In two creative sessions, two groups worked on the two cause clusters of organization and process. For each single cause action field, the affected organizational units and a rough classification were refined. One of the approximately 15 action fields linked to the example topic is the improvement of support by the organization and the process for the flexible use of plant and equipment within the global network.

(2.4) In this step, a broad investigation of fields of action was undertaken to describe the topic in all aspects and dimensions, find interdependencies with other topics/projects/processes and analyze the fields of action in dimensions and scope. One analyzed field of action was "the lack of financial, organizational, procedural support for flexible use of property". In addition, relevant processes/projects and key actors were identified.

Figure 8-5 illustrates the result chain of Cycle 2 beginning with the "to-be" and "as-is" scenarios through an extract of formulated sentences evaluated regarding current fulfilling in company, in step 2.3 the overview of identified causes for deviations, inclusively one concrete cause and in step 2.4 one selected field of action.

(2.1) "to-be" scenario	(2.2) "as-is" scenario = evaluation	(2.3) Causes of deviations	(2.4) Fields of action
Balanced resources and capacities in the production network		Ex.: The lack of financial, organizational, procedural support for flexible use of property	Ex.: Improvement of the support by the organization and the process for the flexible use of plant and equipment within the global network

Figure 8-5: Result chain of Cycle 2 in ZF

8.3.4 Third Cycle: Concrete actions

The objective of the final cycle was the definition of concrete actions related to the fields of action and to position them in the technology roadmap.

Steps 3.1 and 3.2 were merged because the dimensions of the fields of actions were already sufficiently detailed. Three half-day workshops were conducted to further process three dimensions. Chosen dimensions were selected by comparing factors indicating a need for action with factors that already work well. Furthermore, the time estimate was a decision criterion.

Chosen dimensions of fields of actions were broken down into task packages. Like a fine-tuning, concrete actions were described considering the framework of a given evaluation tool at ZF (see step 3.3). The target was

to elaborate ideas in-depth, so that evaluation questions could be answered. Actions were then packaged into innovation projects briefs that are technology specifications at ZF. The project briefs would have the following rough outline structure: problem description, measurable objectives and indicators for success, methodology, opportunities and risks, estimated cost, key stakeholders and estimated time frame. Figure 8-6 illustrates an example, "Identification of key data to show the transparency of capacity and capacity utilization (equipment and personnel)", as a concrete action for improvement of support by the organization and the process for "the flexible use of plant and equipment within the global network". For confidentiality reasons the technology specification is not illustrated in greater depth.

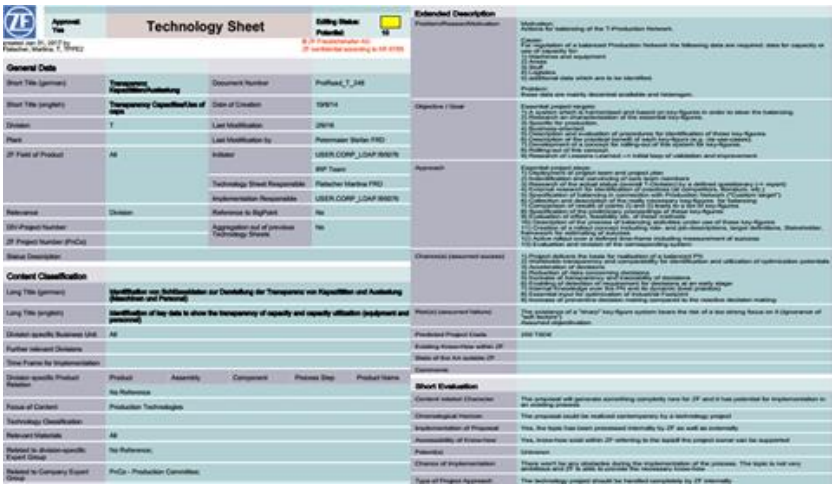

Figure 8-6: "One pager" = Technology specification sheet from ZF

Additional technology specifications refined were:

- Collection and holistic analysis of concrete application cases of flexibility for one/several machines/property and equipment.
- Create a role definition for the future Div. T production network (e.g., gear-boxes).

Further key information in the technology specifications are relevant links to other ongoing projects, in particular (company-wide) strategic initiatives. 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 technology specifications sheets were refined in the teams during the ideation sessions and presented in greater detail in the post-processing phase. The diversity of issues confirms that not only pure technology topics were refined.

(3.3) ZF already has a systematic approach to evaluating technology specifications. In collaboration with the University of St. Gallen, ZF developed a method to evaluate advanced technology projects described in data sheets. The character from these projects is tantamount to concrete ideas arising from the Cycle 3 of IRP SPP. Twenty-seven questions concerning evaluation criteria are illustrated in Figure 8-7.

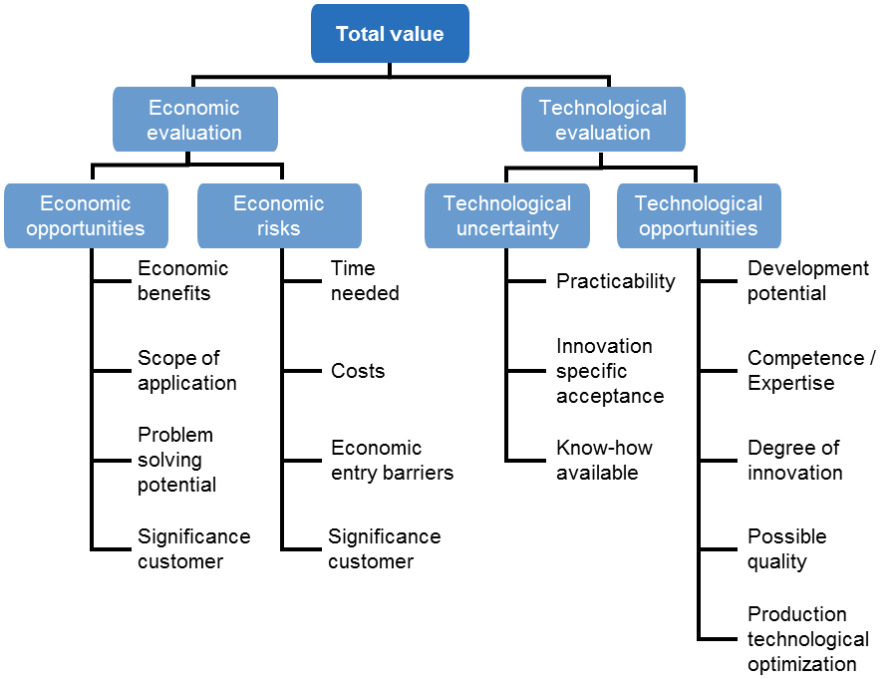

Figure 8-7: Evaluation criteria in ZF

Depending on the topic and the type of evaluation criteria, departments were asked different questions. Thus, not everybody had the same number and type of questions. For example, it is not meaningful to ask the production staff if the topic is innovative. This must be answered by people who have an overview and who have to think strategically in their jobs. For example, the evaluation criteria technical feasibility has the question “From a purely technological point of view, how likely is it that the topic proposal is implemented?” One criteria can have several questions. Equal weight is assigned to each evaluation criterion.

A list of questions (query catalogue) is compiled and questions are evaluated based on their significance at reaching a representative result. The workflow of a project can be defined from the idea (described in the characteristics form) to possible implementation

A software tool is developed to support the workflow. The surveyed answers the questions on a rating scale from A to E. "No answer" is a possible answer available with a notice field. The values A to E are assigned numeric values (A=0; B=2.5; C=5; D=7.5; E=10) to calculate the total value of the idea.

Thus, the evaluation approach could be applied. But questions are accepted if they pertain to all types of ideas. However, the one pagers detailed in the aforementioned workshop were not evaluated in the workshop as at ZF there is currently an exhaustive evaluation process for technology specifications, and not all relevant experts for ZF-specific evaluations participated in the workshop.

(3.4) At the end of this pilot, the technology specifications were sufficiently detailed for placement in the TRM. In total three one pagers were formulated. Topics were networked afterwards to see which topics could be assigned to what priority topic aspects from the beginning. This provided a way to see what aspect was worked on and what aspects are yet unprocessed. The aim was to see that coverage of priority topic aspects became more and more complete.

Figure 8-8 shows the result chain of Cycle 3 beginning at step 3.1 with a sample extract with expanded dimensions of field of action, one example of a concrete action, the evaluation options at ZF in the existing evaluation tool, and finally the roadmap filled in with technology specifications. The result of steps 3.3 (the evaluation types of technology specifications in ZF) and 3.4 (the example of a filled roadmap at ZF) in Figure 8-8 are not further revealed for confidentiality reasons.

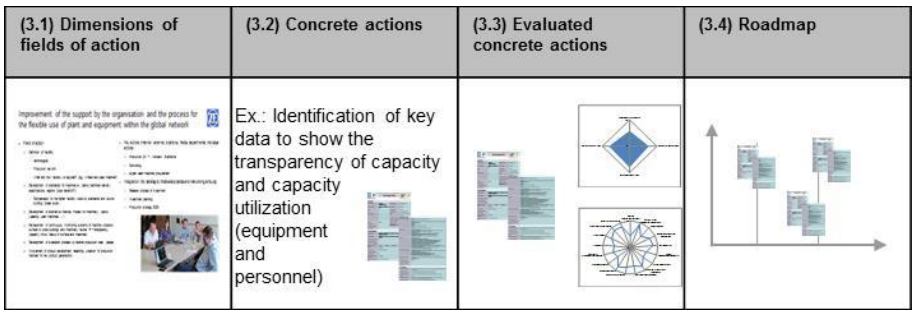

Figure 8-8: Result chain of Cycle 3 in ZF

8.4 Process measurement

Because the IRP SPP was run through in the pilot once, the measurement of the IRP SPP at ZF was applied for this period. These measurement indicators were validated, where it was possible to quantify, in one iteration. As already stated, it is important that, for the indicator values to give a more profound understanding, there must be several measurements taken to develop a reference value. In the scope of this thesis, it was not possible to develop reference values in several measurements. But given values serve as a starting point for further measurements at ZF. In addition, ZF management did not request us to develop a top-down measurement approach.

The measurement indicators (underlined in the following) are presented where it was possible to quantify in one single iteration.

Process capabilities: Workshops indicators

- Number and relative "importance" of members involved in workshops and core team:

Core team/ WS's	Partici -pants	Composition of participants (GP = group production; PD = product development, AD = advanced development; P = production)
Core team	4	1 PD, 2 P, 1 planned from procurement
1. WS	7	1 GP, 5 P Div. T, 1 PD, 1 AD
2. WS	8	1 GP, 4 P Div. T, 2 PD, 1 AD
3. WS	9	1 GD, 5 P Div. T, 1 controlling management Div T, 1 AD, 1 procurement
4. WS	9	1 GP, 4 P Div. T, 1 controlling management Div. T, 1 PD, 1 AD, 1 procurement
5. WS	9	1 GP, 4 P Div. T, 1 controlling management Div. T, 1 PD, 1 AD, 1 procurement
6. WS	9	1 GP, 4 P Div. T, 2 PD, 1 AD, 1 procurement
7. WS	8	1 GP, 4 P Div. T, 2 PD, 1 procurement
8. WS	8	1 GP, 3 P Div. T, 1 P Div. C, 1 PD, 1 AD, 1 procurement
9. WS	7	1 GP, 5 P Div. T, 1 controlling

Table 8-1: Table of members in workshops in case study

- Extent of work effort: Working time in core team and workshop:
  - Core team: Four people in core team coming from product development, production and procurement: 12 core team meetings x 1h = 12h.
  - 9 workshops:

WS	Participants	Hours	Total
WS 1	7	8	56
WS 2	8	8	64
WS 3	9	4.5	40.5
WS 4	9	4.5	40.5
WS 5	9	5	45
WS 6	9	5	45
WS 7	8	5	40
WS 8	8	5	40
WS 9	7	5	35

Table 8-2: Detailed information table of workshops in case study

- Number of ideas: Approaches/projects formally produced:
  - Cycle 1: About 100 ideas
  - Cycle 2: 15 fields of action
  - Cycle 3: 3 concrete actions
- Workshop efficiency: Ratio of detailed results to resources needed:
  - Cycle 1: 100 ideas from 15 participants in WS 1 + 2 = 100/120h = 0.83
  - Cycle 2: 15 fields of action from 8 participants in WS 7 = 15/40h = 0.375
  - Cycle 3: 3 technology specifications from 15 participants in WS 8 + 9 = 3/75h = 0.04
- Workshop effectiveness: aim achievement in %: 100% (Good moderation that steered the workshops and reduced or extended working packages according to time table).

Process capabilities: Communication

- Number of stakeholders involved in at least one IRP SPP workshop: From 75 participants in all workshops, the following 19 were recurring participants: 6 production Div. T, 1 production other division, 1 group production, 2 advanced development, 6 product development, 2 controlling, 1 procurement.
- Number of stakeholders in attendance at IRP SPP presentations: Final event with 15 participants.
- Number of requested IRP SPP materials/presentations/documents by production and others: Technology specifications from the production department group, because expanded working packages were more detailed than previous activities in the group on the same strategic topics.
- Extent of announcement of IRP SPP document within the company between departments: Pilot information was distributed by
  - Minutes of workshops sent to all participants.
  - Final event held: 13 participants (3 group production, 6 production Div. T (management of production Div. T, 2 product development, 1 advanced development, 1 procurement), x 2h (2 new persons) = 26h.
  - 4 articles published in Div. T production newsletter.

  Promotion continues despite a fundamental re-organization of the business division.

Process capabilities: Organizational embedding

- Influence on other departments through IRP SPP results:
  - Workshop participation by employees of product development, procurement and controlling departments.
  - Group production strategy: IRP SPP input and final results viewed.

Process capabilities: Open view of innovation

- Linkage of IRP SPP topics to strategy topics: Obvious linkage of IRP SPP topics to strategy topics, because the production department group wanted technology specification results as completion for their considerations.
- Number of priority topics' dimensions affected through new generated ideas in the whole IRP SPP: Priority topic "Balanced resources and capacities in the production network": Affected dimensions through three technology specifications:

- "Development of role definition for the future T production network using the example of transmissions" → organization, process.
- "Identification of key data to show the transparency of capacity and capacity utilization (equipment and personnel)" → capacity planning.
- "Collection and holistic analysis of concrete use cases for the flexibility of one/more machinery/equipment" → machine planning, controlling.

- Level of involvement of participants with relevant perspectives (dimensions of chosen topic must be addressed) along the process though consultations and active participation:
  - In all workshops the perspective of production and product development was represented.
  - In Cycle 1, where the discussions were on relatively high strategic level, top level managers from production and product development were represented.
  - In Cycle 3, where topics are more concrete, all relevant perspectives were represented, namely controlling, production experts from other divisions and machine planning, so that technology specifications could be fulfilled without missing necessary information.

Process capabilities: Rolling process

- Evidence of accomplishments from previous iterations — may be just anecdotes: Pilot was convincing because top management decided to continue with IRP SPP and to fill core team with top management.
- Run through of all three cycles of IRP SPP in one year: Yes, all cycles could be run through in one year.

Stakeholder: Management

- Level of involvement of senior management team: Time involved with IRP SPP workshops and core team:
  - In core team management met monthly over one year. Twelve meetings of one hour each in one year = 12 hours. If a manager was unable to attend, agreement was reached later in individual meetings with IRP SPP organization team and manager.
  - Senior management in attendance at workshops: Production Div. T: WS1, 3, 4, 6, 7, 9 = 32 hours. Controlling senior management Div T: WS5 = five hours.

Stakeholder: Acceptance

- Overall positive reception of IRP SPP by participants: Yes, based on received feedback, all involved had a positive reception of IRP SPP. Managers were convinced to send their employees to workshops because all benefit from a network in IRP SPP.
- Support of stakeholders for IRP SPP topic: Relevance, involvement, contribution: The manager from the production department group participated in all workshops in IRP SPP from the beginning. He fully supported IRP SPP process and revealed topics because they contributed to his own strategic topics.

Decision-making:

- Duration of aligned prioritization decisions:
  - Decision-making Cycle 1: Nine participants of four hours, in the two workshops. Participants needed to become familiar with the variety of all topics and then made decisions with three priority cards (see 8.3.4) = 36 hours.
  - Decision-making Cycle 2: Four participants in core team of one hour and three hours of preparation work from production department to collect all relevant data for decision-making = seven hours.
- Concrete indicators for prioritization: Decision-making Cycle 1: In the 2 WS all participants choose the most important three topics for them with three colored cards (green = prioity 1, blue = priority 2, yellow = priority 3). Then consolidation of choice in plenum and clustering of chosen topics. The most named topics with first prioritization were chosen in next cycle (see 8.3.4).

Data management:

- Database that documents all topics to consider all trends, avoid blind spots and lose no topic: All topics were documented in the software tool Mindjet MindManager.
- Traceability of idea to trend or priority topic: There was traceability all throughout the minutes and documentation of links to topics in technology specifications. Furthermore, all priority topics linked with detailed findings were documented in Mindjet MindManager.
- Documentation of participants, minutes, workshop presentations, outputs, etc.: Participants of workshops, minutes, workshop presentations, outputs, and pictures from the workshop were saved in a central shared network drive.

- Number of participants with successful access to database (containing TRM results): Central shared network with access for all participants (password protected).
- Documentation of the development of topics over the course of a year: Maturation of topics (how often and thoroughly topics are treated): Development of topics documented in technology specifications (e.g., existing initiative according to topics, open points for topic proceeding) and links to documents in Mindjet MindManager.
- Good quality of IRP SPP results: Complete documentation of detailed information in technology specifications, minutes and Mindjet MindManager.

Applied indicators at ZF conclude that through the verifiable dedicated time in workshops the IRP SPP was set up in a complete way. The work undertaken in creative sessions with multiple proven perspectives (production, product development, procurement, other divisions, controlling) are a form of cooperation that did not exist before and resulted in a positive overall reception of IRP SPP by all participants. The participation of top level management and the demonstrated linkage of IRP SPP topics to strategy topics convinced management to continue the IRP SPP in further iterations. The three technology specifications, which have traceable and demonstrated links to trends, are valid due to the documented decisions that were made about them. This gives the company confidence to work on the right topics and contributes to a process to guide it from determining megatrends to taking concrete actions.

8.5 Process evaluation

Later in this thesis, the IRP process requirement coverage is discussed. The following chapter checks the realization of process requirements for IRP SPP to ensure that the process implemented at ZF is compliant with the IRP SPP cited in Part II. The realization check is formulated qualitatively. Chapter 8.5.2 gives insights into the case study through statements about lessons learned. Chapter 8.5.3 concludes with the added value for ZF.

8.5.1 Process requirements coverage

To demonstrate the feasibility of the IRP SPP at ZF, the single process requirements for SPP (see Chapter 5.2) were now considered to see if realization was successful in the case study. Each process requirement is represented in underlined text, followed by a description of how it was realized at ZF.

Process capabilities:

Be adaptable for relevant process elements considering other relevant processes:

ZF already had a management program for documenting key technology specifications in production topics and comparing them in a roadmap. Therefore, the evaluation of technology specifications and the roadmap were integrated into the IRP SPP.

Ensure the pathway from strategy to implementation and become more and more concrete in subject treatment up to project plans:

The course was accomplished in going from trends to concrete actions. From megatrends, three technology specifications were created that contain concrete actions for priority topics.

Expand the definition of technology, that planning subjects cover SPP holistically:

Undertaking the IRP SPP at ZF brought in topics that were related, but not strictly focused on technology. As the company is already strong in new technology development, the focus was to examine process and organizational topics. But technology was always integral and not excluded from the investigations.

Consider complex demands = open view of innovation:

Very complex and important issues were revealed in the ideation in Cycle 1. Through suitable input the participants were enriched and not overstrained by the presentation of trends. In the following, the systematic steps in the IRP SPP made the complex ideas in Cycle 1 comprehensible. The expansion in dimensions and dependencies with different points of view (production, product development and procurement) increased the understanding of chosen topics.

Enable collaborative networks:

The IRP SPP brought together experts from production, product development, procurement, controlling and relevant group departments, which was new in this format. In the different concretization levels, the participants benefited from having enriching discussions with different viewpoints about important issues, which all participants confirmed in their feedback.

Continuously improve the process:

Through the formation of routines, systematic steps were instituted, so that further operations could be scrutinized for efficiency. Templates to speed up the creative sessions were created. Through the deeper understanding of

chosen subjects, important additional viewpoints became apparent (e.g., to involve controlling in prioritizing topics).

Stakeholders:

The process has to be designed that networking can take place; especially communication, knowledge sharing:

Networking took place through workshops with participants from production, product development and procurement. Moreover, the Cycle 2 and 3 workshops involved several management levels of product development and production or extended the perspectives to controlling when needed.

Ensure that management is aware of the process

Managers in production and product development were highly involved in the pilot. They participated in almost every workshop and met regularly as members of the core team. This resulted in a deeper understanding by managers in the value of proceeding with the IRP SPP, along with their avid willingness to contribute when important production issues and the prioritization of topics throughout the process were examined. In addition, management understood the key element of networking with different viewpoints to proceed holistically.

Bring together/integrate experts coming from different functions and areas at a suitable place from the very beginning

In Cycle 1, participants came from a higher strategic level to consider the global context of SPP. All cycles involved participants from production, product development and procurement. In Cycle 3, very specific experts, such as controlling or employees from other divisions, who participated adapted to the topic.

Decision-making:

Evaluate the planning topics appropriately throughout the whole process & rate collaboratively at all evaluation stages:

The IRP SPP at ZF considered content and process decisions. Content decisions were made in agreement with decision criteria, either in creative sessions with all participants or in the core team with the necessary viewpoints of production, product development and procurement. The decision-making process was adapted to the process step in terms of number of topics, time and resources available, and an effort-effectiveness relationship. Process decisions were made in the core team with input from the production department.

Keep decision-making process of key decisions transparent and traceable, so that performance can be measured:

Decision-making was documented at every decision point in terms of decision preparation and criteria, decision-making technique and involved participants.

Data management:

Appropriately deal with different types of knowledge simultaneously & ensure consistent data management (data quality) in all levels

In the pilot, Microsoft Excel 2010 and Microsoft PowerPoint 2010 were used for presentations, minutes and transcripts. In addition, a central shared network drive was created for all participants in the pilot. The folder had password-protected access to all relevant information generated. Multilayer views of priority topics were modeled with Mindjet MindManager. The evaluation of technology specifications was realized with an internal company tool. Good data quality was achieved by completely documenting all relevant data and assuring that it would be clearly traceable.

8.5.2 Insights and lessons learned

The key target of the case study was to propose for ZF a systematic approach of IRP SPP that addresses the derivation of trends up to actual projects. The case study took one year and participants and top management expressed much satisfaction. The process did not stop after the pilot, but continued in another running with the next Cycle 1 workshop. Although the case study was carried out with limited resources in the pilot project, the stakeholders' experience and results convinced top management to deploy the IRP SPP on the BU level immediately, allowing all three process elements to run through without interruption in one year.

Following are lessons learned from the case study for the next use case:

- It was difficult to motivate and convince key persons in advance outside of production to participate in the IRP SPP. Participation in IRP SPP required a great deal of individual effort. Therefore, without authorization from management, it was difficult to reach the right people, because employees refused from the very beginning to participate. The only way to get employees of non-production departments to participate was to convince managers on a relatively high hierarchical level to send us the right employees for the workshops. This was the only possible way to demonstrate the advantages for all through working together in this format. Furthermore, it must be made clear that managers' experience and knowledge contributed most to the successful

creative sessions all along the IRP SPP. It was also important to accurately estimate the amount of work for managers and their employees in the process.

- In terms of stakeholder motivation, particular attention was paid to establishing and sustaining a clear traceability of the contributions by every single stakeholder to any decision as well as intermediate and final outputs. Stakeholders must have the feeling that their input is appreciated and capitalized on. Input that suddenly disappears in the process without any justified reason will significantly compromise the motivation to contribute further.

- Especially in the core team, the important viewpoints of production, product development and procurement were not always possible. The participation of procurement was hard to acquire because structures in procurement changed at that time and it was not clear who the right contact person was. In addition, it was difficult to involve procurement employees in every workshop because they had other priorities. Although it was clear that the IRP SPP needed the contributions of all, the necessary push by procurement management was lacking and participation was low. The deficient viewpoint of procurement became apparent in the ideation. Efforts were made to make up for missing topics pertinent to procurement in the follow-up steps through individual contact with persons from procurement. As a consequence, procurement expertise was sometimes absent or sporadic. In addition, this deficient point of view affected workshop results.

- A great deal of persuasiveness was needed in individual meetings where all new participants were informed about the process, benefits and tasks. It was essential that the benefit be credible. Therefore, much effort was invested in the preparation of workshops, in particular because the participants changed often and several experts had to be prepared in advance about the context, purpose, and previous happenings. But from the moment that employees participated in the IRP SPP, the process was well received and perceived as enriching.

- Several workshops can be merged to save capacities if scope allows. For that to take place, a workshop must be very well prepared with content wholly tailored to participants. For example, in the second running of Cycle 1 the divergent and convergent step were merged into one workshop.

- Data management in the pilot was not satisfactory in terms of software support. There was no central data management solution that included priority topic visualization in multiple layers, idea management in the three cycles, technology specification management and communication

of information to stakeholders. As mentioned in Chapter 7.3.4, ITONICS is a good software solution. In the final phase of this thesis, ITONICS was introduced and used at ZF. The tool was well received. But the biggest effort was undertaken in Cycle 3—the recording of existing technology specifications.

- The understanding of process flow was increased by wall posters illustrating the three cycles. Central creative elements in the creative sessions were clarified in the posters by illustrations of activities undertaken in the steps.
- The core team became more efficient in preparation and follow-up work, especially in Cycle 1, because it became more understandable over time that these activities speeded up the IRP SPP and increased efficiency in content and decision-making (e.g., which input is really relevant for updating existing knowledge in a priority topic and to finally selecting the topic for further action? Is more ideation necessary or is it sufficient to check strategy conformity and search for missing topics with new strategy input one year later?).
- The consolidation step in the creative sessions was very time-consuming but a critical factor for success. If this step is skipped, results are not documented appropriately and disappear from the minds of participants, leading to a lack of common understanding
- It is crucial to promote the process by disseminating results. Once a year production's priority topics should be presented on strategic level to show all the topics production focuses on.
- It is recommended to create a manual with clear and concrete guidelines for every step of IRP SPP, including an exact designation of departments/employees/roles to involve. This would give production a guide to run through the process at any point.
- The integration of IRP SPP in the organization highly influences the success of IRP SPP, because process credibility increases if results are mentioned in other strategic meetings. It was difficult to achieve the integration in existing processes in the first running because the process was still relatively unknown. But through the involvement of many stakeholders from different organizational units and further iterations, the IRP SPP attracted attention and finally the process has become well known at the top management level. The core team gained higher status though participation by high level managers in production, product development and procurement. This spurred the selection of the right participants for the creative sessions.

- The detailing of the three technology specifications in the case study revealed that more guidance is needed in filling in the sheets. This led to the creation of text fields with suggested response possibilities to inspire and guide the recording of technology specifications. The text fields are oriented to the questions from the evaluation tool.

8.5.3 Added value for ZF

According to the feedback of all involved participants and the experience obtained in the pilot, 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 organization for the elaboration of strategic topics. With increased networking, more stakeholders from different areas are reached and knowledge is ramified in the company to give production experts access to more knowledge.
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 with other ideas and projects.
4. Based on the results and experiences of the case study, the major impact of the ZF IRP SPP is the increased level of information available to the top management of ZF. The innovation activities in production have become significantly more transparent and organized. Figure 8-9 shows how the knowledge-gain structure works in SPP. The knowledge becomes more and more complete. Starting from one priority topic, knowledge is generated in workshops contributing to several aspects of more priority topics. In this way expanded knowledge is documented and linked, so that SPP knowledge becomes traceable and more concrete.

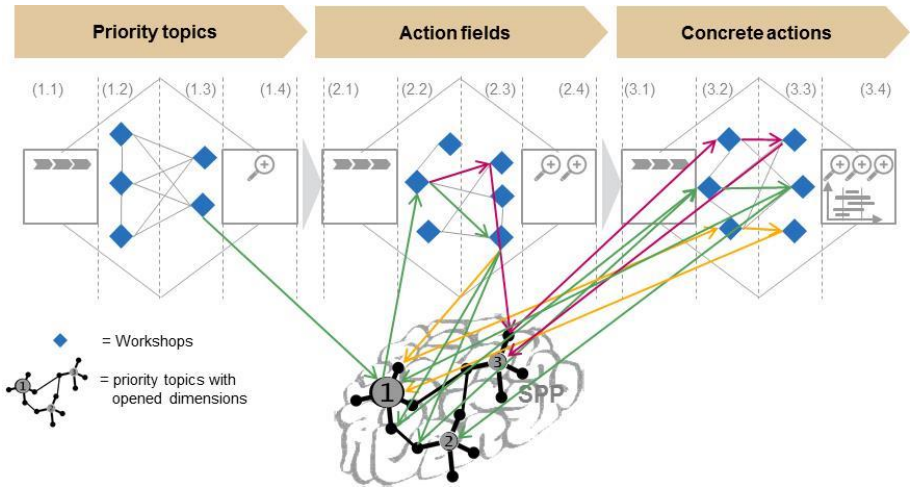

Figure 8-9: Example of knowledge-gain completion in IRP SPP

5. The networked structure of all topics under consideration is always visible and therefore facilitates the holistic view. It is comprehensible why paths disappear and why topics are pursued or not followed up. This is achieved by concretizing subjects more and more in every cycle. Subjects are understood and described in full scope with associated challenges. Subjects are rendered tangible.

Based on these positive experiences and results, the decision was made to deploy the IRP SPP at ZF on a larger scale, adding further iterations to the pilot. These iterations shall lead to the establishment of an internal process manual, as well as a measurement framework based on the KPIs we have proposed.

Part IV:

Global Conclusion

9 Conclusion

Production nowadays is confronted with the uncertain environment of the "fourth industrial revolution", in Germany named Industry 4.0. Therefore, production is confronted with quick and unknown changes in technologies, processes and increasing dependencies of production to other departments, such as product development, procurement and IT. Production, especially SPP, tries to be prepared in this rapidly changing environment by building up technological capacities and distributing given capacities appropriately. To coordinate long-term strategic planning of production technologies in the best possible way with product and system technologies, a holistic integrated view of requirements and solutions to future innovation challenges for product manufacturing is needed.

This thesis focuses on a systematic approach toward strategic planning of innovation driven by manufacturing and facilitated by a TRM approach. Its key contribution lies in the consistent and structured application of approaches and methods inspired by design research and new product development (NPD) to SPP in the form of a stage-gate reference process model. The latter consists of the successful implementation of compiled process requirements derived from a systematic literature analysis (see Chapter 7.3) and detailed IRP SPP process design, comprising three cycles (see Chapter 7.4). In the IRP SPP, megatrends shape the initial input. They are transformed from priority topics to action fields and finally concrete actions. The design element "problem solving in SPP" (see Chapter 7.3.1), inspired by design research findings, builds the central element in every cycle and implements IRP SPP process requirements in a comprehensible and traceable process. The detailed description in Chapter 7.4 shows the process is applicable in big process-driven production settings. Throughout the process, a reasonable effort/effectiveness relationship is pursued.

Furthermore, in Chapter 7.5 a measurement approach is proposed for process assessment and continuous improvement. The measurement consists of three steps to identifying the right measurement indicators depending on the scope of IRP SPP in the different production areas. Developed IRP SPP measurement indicators as well pursue a balanced effort/effectiveness relationship along with feasibility.

The IRP SPP was applied to the corporate setting of the German automotive tier-1 supplier ZF, one of the global leaders in driveline and chassis technology. The process was customized and integrated into this company's existing process landscape. In total the pilot phase of IRP SPP at ZF resulted in 30 priority topics in Cycle 1, followed by 15 action fields in Cycle 2 and three concrete actions in Cycle 3. Within one year, the entire process was run through successfully, driven most notably, by nine highly interactive and interdisciplinary workshops. The measurement was applied to the pilot phase by validating 27 indicators. To measure the success of the process at ZF, it was judged against the degree at which process requirements for SPP were implemented in the aforementioned case study, as well as lessons learned and added value for the company (see Chapter 8.5.1). The decision was made to continue the deployment of the process on a corporate level after the pilot.

The IRP SPP has contributed to increased employee motivation and scope (see Chapter 1.3) and closes some research gaps (see Chapter 5.1), especially the lack of a holistic process for SPP that guides production from megatrends to concrete, tangible planning topics. Through the linkage of SPP planning with NPD research, creative design methods mentioned in research questions from Chapter 6.1 can be answered and research objectives (see Chapter 6.2) can be reached.

10 Limitations

Given the industrial environment in which this thesis was undertaken, as well as some specific constraints, we can identify the following major limitations of this work:

- TRM was selected as a backbone of the thesis to assure the results are in alignment with the current and near-future requirements of industry. Consequently, we did not investigate alternative decision-making support approaches.
- For the same reason, we have chosen a stage-gate architecture for the IRP SPP; however, we have taken into account particular requirements with respect to adaptability and process dynamics. This choice also assures the fulfillment of the requirement for the universal deployment of the IRP SPP in different process-driven industrial environments.
- For the validation of the IRP SPP at ZF, stakeholder involvement was limited to manufacturing technology, product development, procurement and controlling. An even more diverse community of stakeholders could be involved, as the IRP SPP is generic enough to allow the participation of arbitrary expertise profiles and organizational representatives.
- The IRP SPP recommends having all relevant perspectives in the workshops to process the planning topic holistically. But there was no possibility to test work team composition regarding diversity and psychological types. Therefore, it is not clear what combinations of personality traits of participants are more efficient than others.
- Although we investigated measurement approaches for the IRP SPP in Chapter 7.5, we did not have the opportunity to apply and evaluate them consistently in the framework of the thesis. Since we ran through the process only once, we were unable to establish a benchmark based on a prior performance.
- Given the limited time frame and human resources available during the IRP SPP pilot at ZF, it was only possible to apply our approach completely to a limited selection of megatrend and resulting action fields. The detailed investigation of the numerous additional IRP SPP process results

(megatrends, priority topics, action fields, etc.) will be the subject of future IRP SPP iterations at ZF.

- The validation of the IRP SPP has been done in the specific case study at ZF and therefore in the automotive sector. The adaptation and deployment of the IRP SPP in other industrial environments and sectors still needs to be carried out.
- Industries adopting the IRP SPP might have an interest in more guidance for the practical implementation of the planning workshops that are essential for each IRP SPP process phase. Our generic IRP SPP process model provides such guidance only to a limited extent in order to ensure its universal applicability and adaptability to different contexts.

11 Perspectives

Based on the limitations pointed out in the previous chapter, we see the most intriguing opportunities for further SPP research work in the context of Industry 4.0.

- The effective performance of IRP SPP over several iterations in an industrial organization is a highly interesting subject to be investigated. Running through the process several times and addressing different topics will allow for the application of different methods (creativity, workshop moderation, documentation, etc.) in each process phase, as well as the evaluation of their effectiveness.
- Researching the execution of the IRP SPP would also facilitate the establishment and evaluation of a process performance measurement framework based on what has been proposed in this thesis.
- IRP SPP was implemented in the automotive supplier industry. To see how adaptable the IRP SPP is, it should be implemented in more than one industry sector and company.
- Whereas this thesis was focused on the stage-gate model, other process orientations could be researched as the basis for a process architecture.
- The roadmap was chosen as suitable tool for SPP to guide production from trends to concrete actions and has been fruitful. Other tools should be researched as to how suitable they would be for the given context.
- Moreover, further research should be conducted in the networking behavior of production and product development departments when IRP SPP is running through in several iterations. That means how strong and in what way do the departments grow together through collaboration in creative sessions?
- Regarding sessions as an immediate consequence of the aforementioned increased collaboration of different departments, it would also be interesting to investigate the challenges and added values of coming up with an integrated innovation roadmap that covers strategic planning aspects linked

to several organizational units, in particular production, product development, procurement, etc.

- The scope of IRP SPP starts with preparation step 1.1 for priority topic ideation. To guarantee a good start, further research could be done in the previous step to identify trends as suitable input at the start of an IRP SPP. The input should cover the huge range of megatrends and reduce the "good" trends to a manageable number.
- We observed that in the practical application of the IRP SPP, the scope of investigated ideas related to trends, action fields, etc. can quickly become huge (with respect to the number of topics investigated) and complex (in terms of interrelationships between topics). We identified a need for effective ways of visualizing this set at any point in time during the IRP SPP execution. Having related visualization tools at hand can be considered a key facilitator for stakeholders' involvement and would aid in the understanding of complex subjects. Furthermore, we could also visualize to what extent progress made on one or several subjects also helps to advance related subjects.
- Further research should be done in suitable tools or methods to support IRP SPP. For example, an investigation of creative techniques could enrich the operation of an IRP SPP through the selection of suitable techniques per associated cycle.
- The IRP SPP was validated in a German work culture with 15 workshop participants. It would be interesting to investigate how creative ideation sessions operate in other work cultures.
- Moreover, further research could be undertaken in the psychology of team composition related to levels of participant diversity in group work. Work efficiency arises if the personalities of participants are well coordinated and members motivate each other through their way of thinking and acting.

As far as the further application of the IRP SPP at ZF is concerned, the results of this thesis have led to plans for a company-specific IRP SPP to be established at ZF. Further iterations of the cycles will be carried out according to this process, which will be completely integrated into the ZF process landscape.

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Résumé

La quatrième révolution industrielle confronte les organisations industrielles aux défis importants de l'innovation manufacturière, défis auxquelles les entreprises tentent de faire face en utilisant des approches de la planification stratégique de la production (PSP). Les niveaux de risque et d'incertitude intrinsèquement liés aux activités de PSP sont motivés par la nécessité de réagir à la pression en matière d'innovation qui augmente rapidement dans les entreprises industrielles, en particulier dans les secteurs axés sur la technologie tels que l'automobile. L'impact de l'innovation dans la fabrication sur les performances mondiales d'innovation de l'entreprise est plus élevé que jamais, donc il est nécessaire de passer à la prochaine étape de la PSP traditionnelle.

Dans ce contexte, cette thèse propose une approche méthodologique structurée à la PSP qui repose principalement sur l'utilisation systématique de la créativité et de l'expérience d'un vaste réseau d'employés pour établir un modèle intégré pour un processus de PSP basé sur les feuilles de route technologiques.

En partant d'une analyse systématique des exigences à un tel processus à partir de la littérature scientifique et des expériences pratiques, les concepts de la conception intégrée sont utilisés afin de proposer un modèle de processus générique pour PSP. Partant du niveau des mégatendances, ce modèle de processus guide les parties prenantes venants de diverses unités organisationnelles à un niveau très concret des fiches de projet placés dans la feuille de route d''innovation de l'organisation. Le processus de base repose sur des phases succinctes de réflexion divergente et créative et de consolidation convergente et ciblée pour la prise de décision. Grâce à une approche d'orientation structurée, le processus aide les parties prenantes à atteindre le niveau de description du projet à partir du niveau de la mégatendance dans seulement trois cycles de réflexion divergente et convergente, assurant ainsi l'efficacité et la faisabilité pratique du processus. Des indicateurs de performance clés innovants sont proposés pour mesurer les performances des processus et permettre leur amélioration continue.

La faisabilité et l'efficacité du modèle de processus proposé ont été validées avec succès auprès du fournisseur automobile de premier rang ZF Friedrichshafen AG en Allemagne, en tenant pleinement compte du contexte, des exigences et des contraintes spécifiques de cette entreprise.

Abstract

The fourth industrial revolution confronts industrial organizations with fundamental challenges to manufacturing innovation which companies attempt to face by employing strategic planning approaches. The high levels of risk and uncertainty intrinsically linked to such planning activities are driven by the necessity of reacting to the rapidly increasing innovation pressure exerted on manufacturing companies, in particular in technology-driven sectors such as automotive. Since the impact of innovation in manufacturing on the company's global innovation performance is higher than ever before, there is a need for taking traditional production planning to the next level.

In this context, this thesis attempts to provide a key contribution to the creation of a structured methodological approach to strategic production planning that is based on systematically leveraging the creativity and experience of a vast, diverse network of employees to establish an actionable, living integrated process for manufacturing-driven innovation roadmapping.

Departing from a systematic analysis of requirements to such a process both from literature and practice, concepts from integrated design research and practice are used to propose a generic process model for strategic production planning supported by a technology roadmapping approach. This process model has been designed in such a way that it guides stakeholders from various organizational units through the creative planning process from the rough level of megatrends to the very concrete level of actionable projects positioned in the organization's innovation roadmap. The basic process relies on subsequent phases of divergent, creative thinking and convergent, focused consolidation for decision-making. Through a structured guidance approach, the process helps stakeholders reach the project description level from the megatrend level in only three cycles of divergent and convergent thinking, thereby assuring the process' efficiency and practical feasibility. Innovative key performance indicators are proposed for measuring process performance and enabling its continuous improvement.

The proposed process model's feasibility, effectiveness and efficiency were successfully validated at the German automotive tier-1 supplier ZF Friedrichshafen, fully taking into account the company's specific context, requirements and constraints.