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Approach to create transparency on the efficiency of R&D processes by applying Value Stream Mapping

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Efficiency in research and development (R&D), or more precisely in innovation processes, is to be considered as generating, evaluating and developing ideas in order to create new products, processes or services in a short period of time. Comparing innovation processes with e.g. production processes from the degrees of freedom point of view, innovation processes tend to be more creative. Therefore, the controlling of these processes in terms of efficiency is not widely used within companies due to the lack of key performance indicators. Whereas many performance indicators are available and are used to control the efficiency of production processes. Value stream mapping as a fast and easy approach to create transparency on the efficiency of production processes by analysing the key characteristics of the production process (value adding and waste) is commonly used within companies.

This paper depicts analogies and differences of innovation and production processes in order to discuss the transferability of value stream mapping to create transparency along innovation processes' efficiency. Therefore, the stage-gate-process as reference innovation process will be analysed in order to derive main measurable key performance indicators of stages and gates. The present work focuses on the conceptual introduction of R&D-Value Stream Mapping in the academic discourse and as a basis for testing this methodology in practice and will conclude in a critical assessment.

1. Motivation

Especially in high wage countries, the innovativeness of secondary and tertiary sector companies determine their competitiveness and hence their business success. Those who innovate the fastest and close-to-market demands usually grab a competitive advantage. Unsurprisingly, two-thirds or more of companies see innovation among their top-three priorities, even in periods of economic recession (Wagner et al., 2013: 4). The importance of R&D in companies can be described by its three major strategic purposes that are (1) "to defend, support and expand existing business", (2) "to drive new business" and (3) "to broaden and deepen a company's technological capabilities" (Roussel et al., 1991: 17).

The need for companies to measure their efficiency within innovation is described by Werner (2002: 31). On the output-side, shortened product lifecycles, decreases in sales numbers and revenues per product during the lifecycle along with strong competitive environments lead to lower margins and economies of scale resulting in longer-lasting payback times of R&D expenditures. On the input-side, the number of R&D activities increase due to technical progress, changing customer needs and strong competitive environments. Furthermore, R&D tends to get more expensive due to demanding requirements, complexity of technology and contemporary social demands.

In order to handle the increasing pressure on the efficiency of R&D activities, companies can influence the cost and duration of R&D activities in different ways along the innovation process by technology and innovation management

In order to manage technology and innovation effectively and efficiently, the basic "lean management" principles to avoid and eliminate waste or to convert it into value respectively (Womack and Jones, 2003) are applied to technology and innovation management. Therefore, the lean management principles of generating value for customers, determining the value stream, realizing a constant flow along all processes, realizing pull-principles and gaining perfection by continuous improvement are adapted to innovation management and the associated process (Schuh, 2013).

The motivation for this paper came up when analysing technology and innovation management processes in small and medium sized companies. It is quite common that SMEs generate many ideas to improve their products and processes, but face inefficiencies in developing ideas to market-ready innovations. The most frequently mentioned problems are lack of time and coordination of organizational interfaces.

This paper aims to illustrate the conceptual introduction of "innovation value stream mapping" (IVSM) in the academic discourse and as a basis for testing this methodology variant in a real-world environment. Therefore, the traditional value stream mapping will be introduced briefly by explaining the basic approach and showing the basic symbols used in practice (section 2). In order to discuss the transferability of value stream mapping on R&D or innovation management, the analogies, similarities and differences between production and innovation processes will be discussed (section 3). In section 4, basic concept for the use of value stream mapping in the innovation context is introduced. Section 5 addresses the potential of IVSM in practice by critically discussing the present paper.

2. Value stream mapping

Like the lean principles mentioned above, value-stream mapping (VSM) as one well-established and effective method to identify the value stream and to assess it with respect to the lean principles, originates from the context of production management and production processes (Rother and Shook, 2003). The basic method aims at mapping the material and information flow "as a product makes its way through the value stream" and to visually represent every process in an easy and efficient way.

As VSM, as part of the value stream design process in production management, has been enhanced by further aspects over the past years (as discussed in e.g. Edtmayr et al., 2013), this section will focus on the basics of VSM, structured in basic approach and symbols used within VSM. Hence, the further value stream design process steps of evaluation, future state development and implementation are not discussed within this section.

2.1 VSM approach

The basic VSM process steps aim at the current state analysis of value streams from front to end of a production process of a certain product family within a certain factory by mapping the material and information flows (Rother and Shook, 2003). This process is structured in (1) drawing of a rough value stream to depict the whole production processes, (2) collection of information for each of the production processes, (3) collection of inventory between to processes and (4) identification of material and information flow dependencies as well as control principles.

The basic information collected comprises information about customer order (takt time), cycle time of processes, setup time, equipment efficiency, lot size, number of workers, number of product variants, container size, net working hours, scrap rate and rework rate.

The basic material and information flows linking production processes to each other and with suppliers (front end) and customers (back end) are provided with information about regularity and type of transfer (see figure 1).

The basic control principles distinguished are "push" (material flow triggered by forecast information/ production planning) and "pull" (material flow triggered by actual customer need).

The basic performance indicator within VSM is the ratio of throughput time and overall processing time measuring the degree of flow within the process.

2.2VSM symbols

The basic VSM symbols are depicted and briefly explained in figure 1. The selection of basic symbols depicted in figure 1 was done according to their most likely applicability within IVSM.

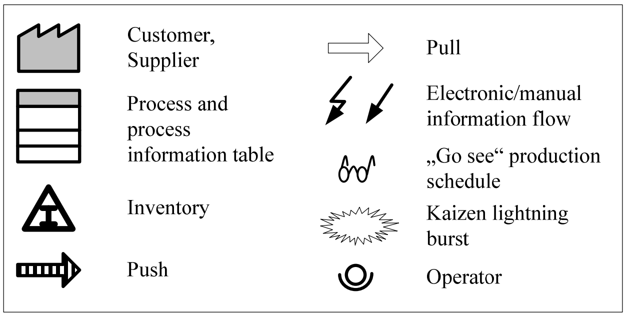

Figure 1. Basic VSM symbols (Rother and Shook, 2003).

3. Transferability of VSM on the innovation process

The primary purpose of VSM is to create transparency along production processes in order to highlight basic inefficiencies in a “quick and dirty” way. However, production processes differ from innovation processes in several aspects. Therefore, it is necessary to point out the major characteristics of both, production and innovation processes, in order to compare them and to discuss the transferability of VSM on innovation processes.

As production and innovation processes both are business processes, it is reasonable to initially point out the key characteristics of business processes. Thus, business processes are a set of (partially) ordered purposeful and dependent activities carried out in collaboration, taking one or more kinds of inputs and creating output that is valuable for outside agents or customers (Lindsay, Downs and Lunn, 2003). The generic performance indicators of processes are effectiveness (“doing the right thing”) and efficiency (“doing things right”) (Becker, 2005: 11). Effectiveness measures if the output of the process meets the targeted goal whereas efficiency measures the input/output ratio with the aim of minimizing input to achieve a certain output. Basic optimization objectives within process management are time, cost, quality, flexibility and employment of capital (Becker, 2005: 12).

3.1 Characteristics of production processes

The generic assignment of production processes is the transformation of raw material and semi-finished goods (input) in finished parts or products (output) by using existing or purchased resources (e.g. Westkämper, 2005: 195; Becker, 2009: 7). Input, output and resources within production processes are also described as objects within the transformation process (1) with identified attributes, that are (2) available and (3) relevant (Dykhoff, 2006: 20). Objects in production processes are material (e.g. material, energy) and immaterial (e.g. intellectual rights, information, workforce) and can be determined in terms of quality. Furthermore, objects in production processes can be measured quantitatively whether they are material (e.g. units, weight) or immaterial (e.g. existent vs. not existent). This leads to the first basic characteristics of production processes: They are distinct, predictable and their input, throughout and output is quantitatively measurable.

As mentioned in section 1, VSM is primarily used within production processes designed according to the flow principle. Therefore, considering the morphology of production type and principle (Westkämper 2005: 198), the production type’s serial and mass production are suited best to apply VSM. Due to the trend to individuality of products along the last decades, serial production more and more is characterized by assemble-to-order production types with high variety (e.g. Dürrschmidt 2001: 21). The key characteristics of flow production processes are (1) produced output of one process is identical (standardized) or at least similar, (2) input per output is constant and (3) processes are repeatable without modification (Westkämper, 2005: 199).

3.2 Characteristics of innovation processes

Technology and innovation management as a cross divisional function has the objective to plan, execute, regulate and control all activities within the scope of innovation and can be divided in a normative, strategic and an operational level (Albers and Gassmann, 2011: 5). Whereas the normative level comprises vision, mission, value and general principles of innovation within the company, the strategic level deals with the internal perspective (resources, technologies, knowledge and competences) as well as the external perspective (markets, customers, suppliers, cooperation and competition). This paper focuses on the operational level of technology and innovation management comprising the design and management of the innovation process. The main subject-matter of technology and innovation management is managing knowledge by identifying, gaining, developing, transferring, storing and using knowledge.

The innovation process includes all actions to create distinct improvements that generate (push) or meet (pull) a certain demand in a technical (product, process), organisational (structure, culture, system) or business (branch structure, market structure) manner (Werner, 2002: 22; Hausschildt and Gemünden, 2011: 25; Zahn, 1995: 27). Over the years, the innovation process thinking has changed from a “logically sequential, though not necessarily continuous process, that can be divided into a series of functionally distinct but interacting and interdependent stages” (Rothwell, 1994: 9) to a rather integrated and parallel process with “a degree of functional overlap with intensive information exchange” (Rothwell, 1994: 12) enhanced in speed and cost matters by the use of information technology along the process. Depending on the type of innovation (technology push vs. market pull), the innovation process is more a process of trial and learning; or a structured process, respectively (Schuh, 2012: 30).

The most established conceptual and operational map for a structured innovation processes is the "Stage-Gate" by Robert G. Cooper (Cooper, 1983). The Stage-Gate is a framework to improve innovation processes effectiveness and efficiency and consists of a series of stages, where R&D work is done, followed by gates, where go/kill decisions are made (figure 2).

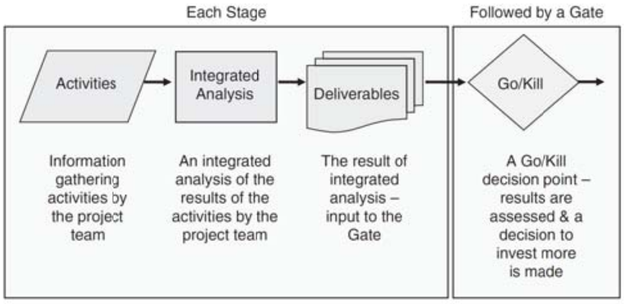

Figure 2. The Stage-Gate principle (Cooper, 2008).

The typical Stage-Gate system for major new product developments is a five stage, five gate system depicted in figure 3. Each stage is "composed of a set of required or recommended best-practice activities needed to progress the project to the next gate or decision point" (Cooper, 2008: 214). "Gates serve as quality-check points, go/kill and priorization decision points" (Cooper, 2008: 215). The reference process depicted as linear process is in fact a series of cross-functional stages with activities occurring in parallel. Stages can entail loops and iterations and can overlap other stages. Stage-Gate is a flexible framework that can be adjusted, e.g. depending on the risk-level of projects and activities. Deliverables can be moved to other stages or bypassed.

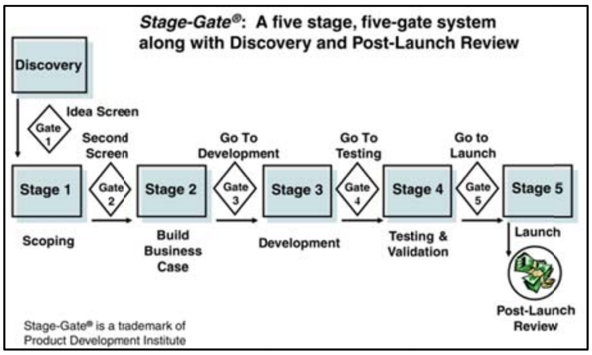

Figure 3. The Stage-Gate process (Cooper, 2008).

In terms of effectiveness of innovation management, the four basic requirements are: (1) the identification of new trends and possibilities, (2) a selection process comparing and prioritising active and inactive projects with respect to available information, (3) a development process helping projects to meet their objectives within a short time and (4) a communication process empowering organisations to work collaboratively and focused (Wördenweber and Wickord, 2008: 11). In order to measure the effectiveness the Technology Value Pyramid (TVP) classified 33 R&D metrics in foundation (practice of R&D processes to support innovation and asset value of technology), strategy (portfolio assessment and integration with business) and outcome (value creation) (Tipping, Zeffren and Fusfeld, 1995). More recent surveys on R&D metrics on basis of the TVP identified additional metrics and metrics groups (open innovation metrics, metrics on the effectiveness of R&D processes beyond financial, value creation metrics for services, not-for profit metrics) and rated them. As in the original study the top ranked metrics are mostly financial (e.g. financial return to the business, gross profit margins, gross profits from new products, projected value of R&D pipeline), non-financial metrics are e.g. product quality, accomplishment of project milestones, customer ratings and number of technical reports (Schwartz et al. 2011: 32).

Measuring efficiency of innovation processes and projects in terms of minimal input/output ratio is challenging, since input and output are not directly dependent or highly time-delayed in innovation projects, especially in early stages (Schuh, 2013: 144). Nevertheless, efficiency can be evaluated quantitatively using target-performance comparisons with respect to time (e.g. time-to-market, time-to-profit), cost (e.g. internal R&D expenses, external technology expenses) and progress (e.g. deliveries, patents) (Werner, 2002: 64). The main success factors for efficiency in innovation processes are comparable to the lean-thinking principles of waste elimination in production processes.

3.3 Comparison of production and innovation processes with respect to the use of VSM

The comparison of production and innovation processes is done with regards to the criteria "input", "output", "resources", "metrics", "organization" and "value stream". Table 1 summarizes the comparison of characteristics discussed in sections 3.1 and 3.2.

Criteria	Production Process	Innovation Process
Input	• material and immaterial • identified attributes	• immaterial • not clearly identifiable attributes
Output	• material • clearly predictable in type and time	• immaterial • not clearly predictable
Resources	• personnel • material and immaterial	• personnel
Metrics	• quantitatively measureable • effectiveness and efficiency are evaluated using precise operating figures	• quantitatively and qualitatively measureable • effectiveness and efficiency are evaluated using target-performance comparisons
Organization	• organizational unit	• cross-functional
Value Stream	• linear	• non-linear

	• distinct • repetitive • specified process	• unpredictable • non-recurrent • process framework to be customized

Table 1. Comparison of production and innovation processes.

The comparison of production and innovation processes shows that there are major differences in terms of number of degrees of freedom: Production processes are highly projectable and linear, whereas innovation processes are confronted with uncertainties that need to be handled by customizing the process according to the problem to be solved and rework loops within stages of the process. However, the two types of processes share the input-output process thinking; effectiveness and efficiency can be measured. Both processes aim at generating value for the customer as fast as possible and share the goal of realizing a flow along the value stream. In order to gain efficiency, it is necessary within both processes to identify and eliminate waste according to the lean management principles. Production processes and innovation processes have analogies regarding the basic waste categories such as over production (e.g. work is done without order (push not pull), unnecessary level of detail), rework or scrap (e.g. wrong data and information, failure in design), inventory (e.g. too much data, old data, too many projects), unneeded work (e.g. unnecessary process-steps, unneeded re-design) (Schuh 2013: 145). Waste is also generated by missing or inadequately used methods and tools (Wördenweber and Wickord, 2008: 14) as well as intransparent communication paths (Boehm 2013).

4. Concept of innovation value stream mapping (IVSM)

The idea of applying VSM on innovation processes has already been discussed by Cooper (2008) and Schuh (2013). In order to identify inefficiencies, mostly in terms of time wasters, "all the stages, decision points, and key activities in a typical project are mapped out, with typical times for each activity and decision indicated" (Cooper 2008: 225). After examining the process at its whole, critical stages are analysed in detail. Compared to the production VSM, the exemplary value stream map depicted by Cooper (2008: 226) does not use VSM-typical symbols and time lines. Cross-functionality is indicated by listing the functions integrated in the process-step.

Another approach to use VSM in the innovation context is introduced by Schuh (2013: 150): The modelling language "aixperanto" uses graphical symbols in order to depict the value stream in innovation processes. This approach uses process tables entailing information about process times, resources, inventory, scrap rates and different graphical symbols if the process is value adding and standardized or not and symbols to depict control mechanisms. Furthermore, a swim lane design is used to assign process steps to organizational functions. However, the cross-functionality within one process is not shown in the exemplary value stream map.

4.1 Requirements of IVSM

One basic requirement of IVSM is to depict the innovation process in a comprehensive way. To do so, the granularity of analysis is to be chosen adequately. Basic stages and gates of the Stage-Gate framework need to be mapped. Organizational functions that drive (the responsible division) and those who are involved in each process step, personnel capacities as well as process information and inventory are to be displayed. As innovation processes are not sequential, it is also important to depict loops along the innovation value stream.

Furthermore, it is necessary to highlight the control principles push vs. pull). Inefficiencies or problems regarding effectiveness in stages or gates are highlighted using Kaizen lightning bursts. As innovation processes comprise the management of information, the information flows as well as information databases used need to be transparent in terms of relation and media discontinuities.

For the practical use of IVSM it seems necessary that the map can be easily drawn (pen and paper), entails the relevant information named above and still is well-arranged. As VSM-symbols in production management are common, the IVSM approach introduced in this paper resorts to the traditional symbols exemplarily depicted in figure 1. In order to consider innovation processes characteristics, some additional, easy-to-draw symbols are introduced in the following section.

4.2 Additional symbols used within IVSM

The additional symbols used within IVSM are depicted in figure 4.

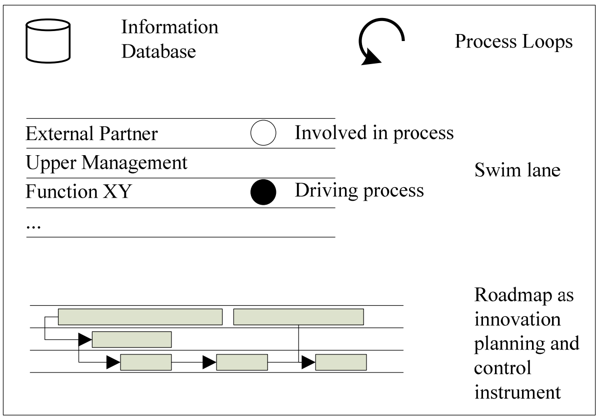

Figure 4. IVSM symbol amendments to traditional VSM.

In order to create transparency on information flows it is necessary to depict information databases used along the innovation process. Project experience shows that databases are often decentralized and thus unknown to relevant function owners with respect to existence and content. As the innovation process is not sequential, process loops are considered by loop-arrow and rework-quota due to loops (see process information table depicted in figure 5).

Cross-functionality along the process and within certain stages is incorporated by the use of a swim lane design and indications whether the function is driving the process or is involved in the process as support. In analogy of production planning and control systems in the traditional VSM, a technology-roadmap symbol can be used if utilized in the company under consideration.

Arrows to highlight control principles along the process show if R&D is more incremental (targeted development and therefore "market pull") or more fundamental (scientific research, "technology push")[1]. Inventory, depending on the degree of maturity along the innovation process, can either be ideas or projects that are in the pipeline.

Stage XY	
# personnel	Main tasks: • … • …
Process time	
Personnel full-time-equivalent	
Personnel overall efficiency	
Capital employment (budget)	
Rework quota due to loops	
...	

Figure 5. IVSM process information table.

According to the process information table, the traditional information is enhanced by main tasks to be accomplished within the stage. This is necessary as the Stage-Gate needs to be tailored with respect to the company's needs. Tasks suggested in Stage-Gate can be bypassed or moved to another stage. After all, it is vital to create transparency of all tasks accomplished along the process in order to identify inefficiencies or missing tasks.

Another challenge within innovation processes' efficiency is personnel allocation to the process and stages. Therefore, it is necessary to display the number of staff involved in the process, the full-time-equivalent effectively working on innovative tasks as well as their overall efficiency. Personnel overall efficiency within this context is the ratio of value-adding time to full-time-equivalent of personnel. Value-adding tasks are those directly advance the idea/project whereas non-value adding task comprise e.g. general trainings, administrative tasks or dissemination activities. Capital employment indicates the financial resources allocated to the process/stage. In terms of efficiency, the actual process information should be related to values planned. Media discontinuities can be displayed using different arrows for manual and electronic information flows but can be enhanced by abbreviations regarding document formats or systems used. An exemplary overall IVSM is depicted in figure 6.

4.3 Propositions on the procedural method and interpretation of IVSM

In the course of several projects in small and medium sized production companies, mainly in Austria, audits in order to identify optimization potential within their innovation and R&D processes were conducted. We started doing this from start to end of the process, thus starting with strategic issues, idea generation, idea evaluation and selection, project portfolio management, technology-roadmapping, production process interdependencies etc.. On the basis of our structured questionnaire, relevant cross-functional employees self-assessed their innovation process on the basis of an easy traffic light system. We experienced that the evaluation results tended to be positive, even if there were basic inefficiencies, e.g. in aligning product and production development.

We then changed the order of questioning starting with questions about the last "real innovation", thus the last idea with market success, and about the process from end to front. Upon this company specific best-practice-example other less successful R&D projects were discussed. We do not have any statistical proof on that, but we experienced a much more critical dispute with the innovation process employed within the company and could easily identify improvement potential regarding effectiveness and efficiency in analogy to lean principles. Therefore, just as the traditional VSM approach, we suggest to start the IVSM from end to start, comparing effectiveness metrics and efficiency indicators with regard to values planned and experiences from similar (successful and failed) R&D projects. To do so, projects need to be structured in families with respect to R&D types just as building product families within traditional VSM. It is appropriate to generate different maps for each R&D type.

The interpretation of the innovation process(es) mapped can comprise several aspects:

1. *Collection of data*: If the data required is not available, the first potential is already identified. In order to improve the innovation process, the introduction of company-specific and meaningful metrics is vital.
2. *Process times, inventory and personnel allocation*: As in traditional VSM sub process lead times, idle periods and overall lead time can be calculated. In analogy to the customer takt time in production processes, industry common product life cycle durations can be used to show if innovation processes meet customer requirements
3. *Changes in inventory along the pipeline*: the innovation process should reduce the amount of initial ideas to those with high potential as fast as

[1] R&D type characteristics according to Roussel et al. (1991: 15)

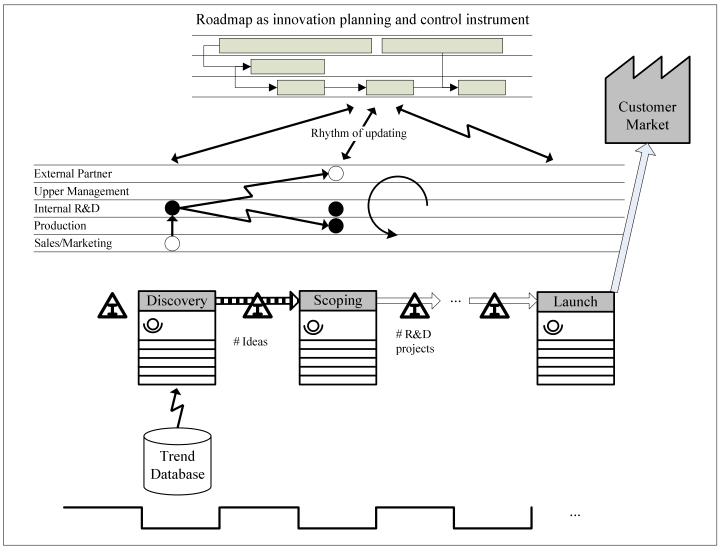

Figure 6. Exemplary Innovation Value Stream Map.

possible in order to allocate financial and personnel resources effectively and efficiently. If the idea-funnel does not narrow, there is optimizing potential e.g. by improving decision criteria within gates or integrate relevant decision-making authorities to the gate under consideration.

4. *Information flows*: Efficient and transparent information handling is vital to innovation processes. If information flows intersect or databases are decentralized or unknown, the cross-functional setting should be scrutinized.
5. *Cross-functionality*: It is vital for successful innovations with short times-to-market that the right (internal and external) people are integrated at the right time. If process and lead times in subsequent stages are longer than initially planned, it might be the effect of belated integration of necessary functions or missing decision-making authorities (project driver).

It has to be questioned if tools and methods are used continuously and systematically throughout the process. The use of tools and methods (e.g. portfolio techniques, roadmapping, task analysis) can improve the effectiveness and efficiency of the process directly, as well as the transparency of decision making.

5. Conclusions

This paper shows the theoretical basics of innovation and production processes in order to identify similarities and differences of the both. Production processes are identically repeated linear processes transforming distinct goods with distinct resources and hence important metrics are easily quantifiable. On the other hand, innovation processes are unique problem solving processes mostly handling information in order to improve existing products, processes and services for future market requirements, thus faced with uncertainties. Nevertheless, reference models like Stage-Gate depicture innovation processes as a series of value adding activities. This leads to the basic conclusion that VSM is applicable to innovation processes. The approach introduced in this work is closely based to the VSM well-known in production management. Other approaches to map the innovation value stream do not entail the holistic view on the process or consist of new modelling language patterns.

One basic problem of innovation stream mapping is seen in the uniqueness of specific projects and therefore in the lack of data availability in order to quantitatively evaluate effectiveness and efficiency of innovation processes. The identification of e.g. inventory or process times in production processes can be easily done by counting/measuring in the course of an on-site visit. However, transparency about missing important metrics can be the first step to improve innovation processes and innovation management, respectively.

The benefit of IVSM is seen in the creation of transparency along the holistic innovation process. Due to the cross-functional characteristic of innovation processes, it is of major importance to at least qualitatively map the process with relevant functions in order to identify the general shortcomings and detail the analysis in subsequent activities. IVSM can serve as helpful framework to consider the most important aspects of innovation processes.

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