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Developments of traditional value stream mapping to enhance personal and organisational system and methods competencies

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This paper presents developments of traditional value stream mapping (VSM) related to enhancing system and method competencies of both individuals and organisations. Since systematic immersions in traditional VSM – a highly accepted technique for improving production systems – are necessary, this paper describes from a production research point of view approaches for systematic productivity increases, reduction of lead time and an approach to improve sustainability indicators of value streams. The introduced developments of VSM focus on the entire flow and on details, thus creating synergies for designing and improving value streams, processes and work systems both economically and ecologically. On the one hand, this paper shows how practical approaches respectively rationalisation concepts (Lean principles, VSM, Process Management, short-cyclic improvement routine, Methods-Time Measurement) are used in industry in order to manage and improve processes and value streams. On the other hand, sustainability management can be supported on shop floor with utilisation of VSM. It aims to extend the view on value streams of both researchers and practitioners in sense of system and methods competencies.

Keywords: value stream mapping; productivity improvement; sustainable manufacturing; MTM; sustainable value stream mapping

1. Introduction and motivation

Numerous (manufacturing) companies improved their productivity in the last 10–15 years, based on continuous improvement attempts as well as by applying lean methods. Yet, the success rates of the achieved improvements are lowering while utilising these methods for longer periods of time. This diminishing gradient is determined by an increasingly difficult and expensive identification and elimination of inefficiencies and waste (Abdulmalek and Rajgopal 2007). Therefore, new ideas and approaches in addition to product and service innovations have to be evolved to allow and ensure extensions and immersions of design and rationalisation methodologies in work system design.

So new demands arise for improving value streams and from revealing existing competencies for systematically and methodically planning, target-oriented design, implementation, rationalisation and sustainable improvement of processes and work systems; also from further pooling, interpreting, adapting and developing these competencies. By applying systematic approaches and by concentrating already existing but decentralised personal and organisational competencies, they can be utilised for evaluating improvement measures.

In the last few years, Value Stream Mapping (VSM) (see definition and example in Section 3.4) in particular turned out as an easy to apply yet effective improvement methodology.

2. Need for research

Existing production research literature focuses on shifts in improvement paradigms respectively in production improvement priorities (Ishii 2013; O'Brien 2013), lean, (continuous) improvement or standardisation aspects (Marin-Garcia, Pardo, and Martín 2008; Pettersen 2009; Vinodh, Arvind, and Somanaathan 2010) or publications relating to practical VSM applications (Erlach 2007; Rother 2009; Mahfouz, Crowe, and Arisha 2011; Li 2013) show clear evidence that a systematic, generally accepted further development of traditional VSM is suggested out but not yet

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discussed. A distinguished literature review (Dal Forno et al. 2014) about value stream indicates the challenges of practical VSM application in these days. Therefore, it is necessary for both organisations as well as for individuals to enhance their system competencies and method competencies. It is important to inhibit the application of VSM techniques as a simple drawing tool without focusing on improvement measures (cp. Liker and Meier 2006). Recent published scientific literature suggests a trend in combining VSM with several other approaches or methodologies.

As such, we refer to examples of operations research (Bertolini et al. 2013; Marangoni, Romagnoli, and Zammori 2013; Remenyi and Staudacher 2014) and simulation (Abdulmalek and Rajgopal 2007; Remenyi and Staudacher 2014; Solding and Gullander 2009) approaches and reviews in VSM as well as to several procedures to quantify and revise sustainability metrics following VSM principles (Erlach and Westkämper 2009; Torres and Gati 2009; Paju et al. 2010; Faulkner and Badurdeen 2013; Lourenço, Baptista, and Pereira 2013; Martínez-Jurado and Moyano-Fuentes 2013; Kurdve et al. 2014).

Frequently, VSM is applied to improve or solve unique, specific problems respectively use cases (Lian and Van Landeghem 2007; Yang and Lu 2011). Furthermore, VSM is applied as a rationalisation approach in numerous publications and is used to encourage Lean Management introduction respectively lean thinking in companies (e.g. Bhamu, Khandelwal, and Sangwan 2013; Roosen and Pons 2013). In addition a lot of publications present how VSM is used in several fields to identify improvements. These papers provide evidence for accomplished lead time reduction, productivity enhancement and reduction of inventory.(Singh and Sharma 2009; Chen, Li, and Shady 2010; Green, Lee, and Kozman 2010; Seyedhosseini et al. 2013) in production, logistics, trade, textile industry and medical services (Saleeshya and Raghuram 2012; Villarreal 2012; Xie and Peng 2012). In particular, Schultetus (2001) alludes, that existing methodologies have to be evolved on a scientific base to integrate, to standardise and to utilise them in a generally accepted way.

All in all, these further developments of VSM focus on problem solving in specific use cases or application areas. Hence, we see the need of research in how these opportunities in VSM influence organisations and individuals. On these grounds, certain developments of VSM (Value Stream oriented Process Management, the immersion of VSM by MTM and sustainable value stream mapping (SVSM) have been carried out systematically. This contribution show how these approaches influence and raise personal and organisational system and method competencies and therefore the collective intelligence of companies.

This in-company research in several projects in conjunction with existing theories and models facilitates the applicable knowledge in order to build and evaluate the introduced approaches. So, our research falls into the category of Design Science (Hevner et al. 2004).

Based on Design Science Research Methodology (Peffers et al. 2007) our research the starting point was to identify System Competencies and Method Competencies in findings of specific VSM publications. Scientific publications (primary and secondary) were identified based on a thorough literature search in the fields of VSM connected to Sustainability, Lean Management, Production Systems, Use Case, Process Management, Productivity Improvement, Production Planning and Control. Out of this, we defined approx. 300 relevant publications from 2008 up to today as the state of the art and the most suitable were cited in this paper and its underlying publications.

The paradigm of designing 'ideal' value streams (Spear and Bowen 1999; Hopp and Spearman 2008; Rother 2009; Kuhlang 2012) leads our thoughts. In specific, our previous research is presented briefly as extractions of the underlying publications focussing essential core issues of 'Value Stream oriented Process Management' (Kuhlang et al. 2013) of the immersion of VSM by MTM (Kuhlang, Edtmayr, and Sihn 2011) and Sustainability Management with a VSM approach (Edtmayr, Sunk, and Sihn, forthcoming) are described.

Prior to that, the required fundamentals and the state of the art are depicted.

3. Fundamentals and state of the art

3.1 *Definition of 'competence'*

'Competence' in this paper means that individuals are characterised by competencies, and therefore they are able to organise and apply their abilities, skills and knowledge in combination with experiences, values and norms successfully in known and unknown situations. Competencies are skills of individuals – as a consequence of organisations too – to act self-organised and creative in new situations (Heyse, Erpenbeck, and Ortmann 2010). This disposition for self-organisation is one of the main preconditions while performing target-oriented planning, design, implementation and continuous improvement of socio-technical work systems in order to build productive (efficient/effective) thus economic production/manufacturing processes respectively industrial (stable, deviation-resistant) value streams (Richter and Deuse 2011). The personal and organisational system and methods competencies are contributing to the self-organisation disposition of companies and are therefore described subsequently.

3.2 *System competence*

System competence represents the integral understanding of overall flows and individual performance on a systems' level, in order to guarantee a target-oriented alignment and prioritisation of activities. In other words, system competence connects understanding of overall flows to the capturing and evaluation of deviation in processes. It deduces targets and target conditions from the superordinate objectives (strategic objectives, factory objectives, customer goals, etc.) of the organisation.

Therefore, system competence concerns to a macro-level representing an integrated understanding of value streams, production processes and work systems considering the overall system. It is important to clarify that VSM contributes to a systematic understanding but does not represent the system competence itself. System competence also means interdependencies and dependencies between sub-systems and enables prioritisation of activities. It transforms general vision-related goals to targets at a lower level of detail and defines standards. This understanding is crucial for combining different improvement efforts to superordinate objectives of organisations. Besides, understanding the production system of an organisation and its vision is fundamental for defining consistent and challenging (learn-enhancing and performance-enhancing) target conditions respectively future state maps (FSM). System competence also connotes the comprehension of variability of overall and single processes and work methods of a system, the identification of pacemaker and bottleneck processes, inventory and the understanding of increasing costs due to revolving stocks (Kuhlang 2012).

3.3 *Methods competence*

Methods competence comprises from the ability to apply methods of time determination (e.g. methods-time measurement (MTM) or similar systems) and production system for the definition of target-conditions and standards as well as for the deduction of ergonomically relevant data (i.e. physical load) (Kuhlang 2012). It refers to the application and the understanding of several methodologies, e.g. in Lean Management and Industrial Engineering. Knowing methodologies and tools as well as being able to deploy them is crucial for establishing a comprehensive comprehension of work system design as well as for defining target conditions and problem solving. Methods competence also covers the ability to select and apply useful methodologies and tools which implies a deep understanding of the methods itself, their limitations and situation of application. Therefore, methods competence is associated to expert knowledge (Steffen 2010).

In general there is a wide range of methods and tools available, e.g. for problem solving, planning, improving, analysing and evaluating processes and for managing projects. Hence, it is an organisations' responsibility respectively of its individuals to choose and utilise methods to solve an existing issue and to develop methods further.

3.4 *Value stream mapping*

VSM was originally developed as a method within the Toyota Production System (Ohno 1998; Liker 2009) and introduced as a distinct methodology by Rother and Shook (2006). VSM is an easy and effective way to get a comprehensive overview of the condition of the value streams of an organisation. Based on the analysis of the current-condition (current state map – CSM), flow-oriented target value streams (target-conditions respectively FSM) are planned and thereafter deployed (Rother and Shook 2006; Erlach 2007; Klevers 2007).

A value stream includes all activities value adding, non-value adding and value-preserving (supporting) activities that are required to create a product (or to provide a service) for the customer. This includes the operational processes, the flow of material between the processes, all control and steering activities and also the flow of information (Rother and Shook 2006). In order to identify possible improvement potential, VSM considers, in particular, the entire operating time compared with the overall lead time. The greater the distinction between operating time and lead time, the higher the potential (Erlach 2007). VSM comprises a four-step method (Figure 1) consisting of the steps 'choose a product family', 'draw a current-condition map', 'develop a target-condition' and 'implementation of target-condition' as well as an 'action plan' to monitor the implementation, to describe measures (what, by whom, until when) to improve the value stream.

The ideal-state ('true north') is like an aid to orientation for the definition or specification of the several different target conditions for the processes (Imai 1986; Spear 1999; Deuse, Rother, and Hempen 2009). It is specified by characteristics like (a) customer takt, (b) 100% added value, (c) continuous one-piece-flow, (d) zero defects and (e) lack of impairment for employees. The orientation towards the ideal-state (Spear and Bowen 1999; Liker 2009; Rother 2009; Ballé 2012), avoiding waste (Takeda 2009) and the stockless production system (Edwards 1983) are key elements in the design and rationalisation paradigms of the 'ideal value stream'.

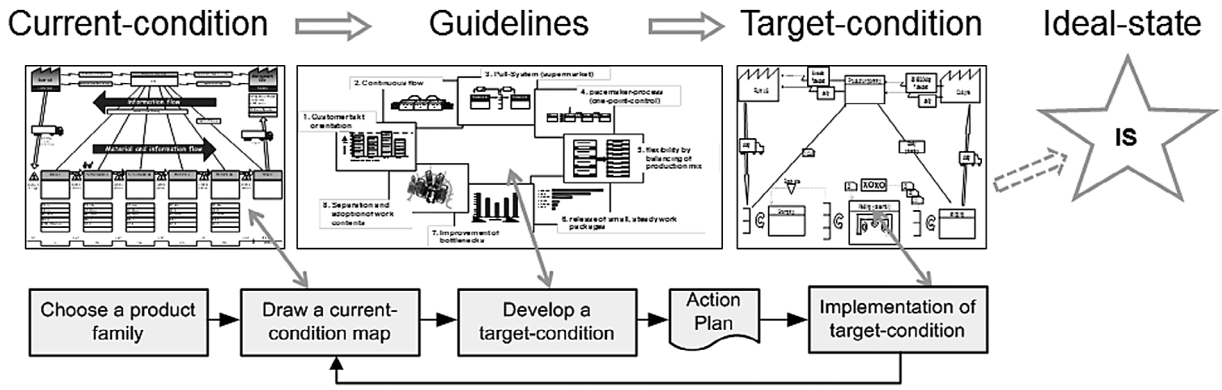

Figure 1. 4-Step-Method and the orientation towards the ideal-state.

The following (design-) guidelines (Figure 1) are suggestions for measures or guidelines for developing target conditions: 'Orientation towards the costumer takt time', 'Continuous Flow', 'FIFO-design', 'Pull-System (Supermarket)', 'Pace-maker processes (One-Point-Control)', 'Flexibility through balancing (of the production-mix)', 'Release of small, rhythmic work loads', 'Removing bottlenecks', 'Separation and synchronisation of work contents', 'Value stream oriented layout'.

Hereinafter, developments of traditional VSM techniques by the authors will be used to demonstrate the enhancement of System Competence and Methods Competence of organisations as well as individuals. Publications regarding (a) 'Value Stream oriented Process Management' which integrates VSM into the management of the Process Life Cycle (PLC)); (b) the immersion of VSM by the systematic combination with MTM to evaluate work methods; and (c) including several aspects of Sustainability Management into VSM (i.e. a waste accounting approach) are described. In fact, scientific contributions of us and other authors to further develop traditional VSM are used in this paper as the fundament to enhance System Competence and Methods Competence of both organisations and individuals. Examples are given in the following sections.

4. Value stream-oriented process management

Companies are confronted with the task of managing, designing and improving their processes in various different levels of detail – so from the main processes down to the operative work methods. Therefore, a lot of concepts and methodologies are used practically and are recommended in literature. In most cases improvement attempts between the different levels are not linked methodically; e.g. a uniform information and data exchange between several improvement attempts does not occur.

Therefore, the following questions of the problem are derived. How can different improvement attempts within different levels of a value stream be combined usefully? How can value streams be managed, designed and improved in a structured and repeatedly recurring way?

Generally speaking a Process Management System is a suitable approach to improve processes in the comprehensive way. Out of the variety of concepts and methods to improve value streams, Value Stream oriented Process Management combines three – broadly practically applied and theoretically well described – approaches (Process Management, VSM and a systematic routine to manage and improve processes). In here the mutual combination of disruptive changes (innovation leaps), and short-cyclic changes (continuous improvement) justify the fundamental approach to improve value streams. Improvements to push processes to a higher performance level can be achieved by these two basic principles (Imai 1986; Povey 1996). From a process-oriented point of view, there is no fundamental difference in appreciation of what a 'process' or what a 'value stream' is. In terms of this paper, a value stream is in most cases a product-oriented flow or extract of processes on a higher level of detail. A value stream may contain different processes from the Process Map or main as well as sub-processes from 'deeper' levels of detail which affect the production of a product (Kuhlang et al. 2013). A value stream itself consists of operative processes and the inherent material and information flows. A 'process' describes those activities of a value stream that are necessary to create a product.

Process management delimits, analyses, visualises, operates, measures, controls, documents and improves processes in order to accomplish customer requirements. The PLC (Figure 2) indicates and determines each stage of the life cycle of a process within a Process Management System. It starts with the integration of the process into the process map and

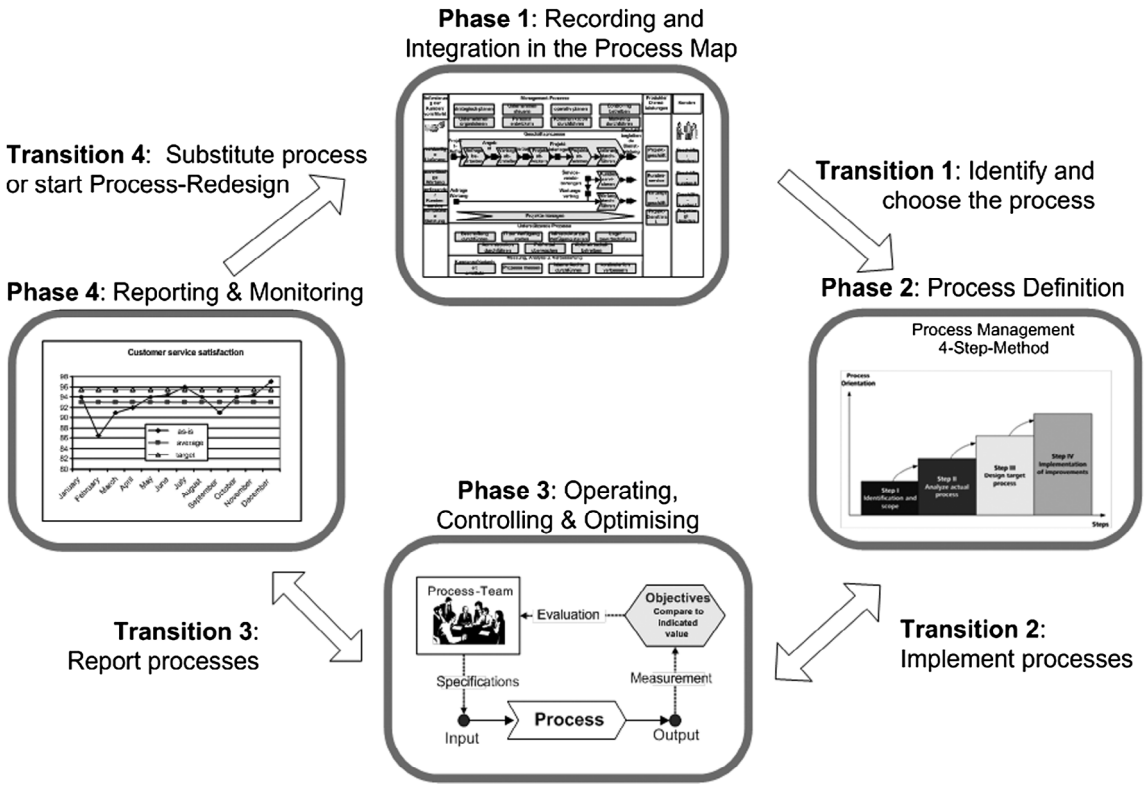

Figure 2. Basic principle of the PLC (Wagner and Patzak 2007, 98).

it ends with the closure down this process. The PLC determines steps in the cycle of a process in the Process Management System in form of phases and phase transitions and is named the 'large control-circuit' in Process Management. Phase 1 'Recording and Integration in the Process Map' and phase 2 'Process Definition' depicts the design and conception of processes. Phase 3 'Operating, Controlling and Optimising' as well as phase 4 'Reporting and Monitoring' portray the recurring ('daily') work of performing and improving processes.

In phase 2 of the PLC, the four-step method is a crucial procedure to determine new processes and to change and improve existing processes. Deploying this procedure usually results in essentially adopted respectively improved processes. The four steps are introduced by a sequence of – at least – four so-called Process Team Meetings (PTM). Each PTM portrays a milestone during a step to ensure the systematic execution of the four-step method. The Process Jour Fixe (PJF) meetings are tools resp. approaches for a continuous control of a process in phase 3 and during the transition to reporting and monitoring in phase 4. During phase 3 –the 'daily life of a process' – is keen on meeting the requirements and on identifying and realising improvement actions – short-cyclic – in the direction of the target-condition. The continuous improvement is assisted by information from phase 4. The reporting and monitoring of different processes and several process goals happens in phase 4. Thus, the information available in phase 2 and phase 3 is broadened by relevant, respectively strategic parameters and aspects. All necessary information, performance indicators and actual problems in the daily life of the process are worked up prior to a Process Management Review. So they are also obtainable for the PJF and the PTM to gain prosperous decision-making and to enable the fundament for deriving necessary improvement measures (Wagner and Patzak 2007).

Process Management enable the organisational framework for the systematisation of VSM. This is based on embedding and integrating a value stream into phases 2–4 of the PLC. This conjunction of continuous improvement and innovation can be found in the Process Management System, in phase 2 and 3 of the PLC and enhances the 4-Step-Method (Figure 3).

The settlement of target-conditions, (during phases 2 to 3 utilising information from phase 4), endorses the PLC by setting well settled intermediate goals along the way to the ideal-state ('true north'). All in all, the systematic improvement of a particular value stream is realised by its embedding into the phases of the PLC; reflecting a interplay of disruptive changes, stabilisations and continuous improvements supplemented by an ongoing monitoring (Kuhlang et al. 2013).

Next to this extension (broadening) a systematic immersion (deepening) of VSM is introduced.

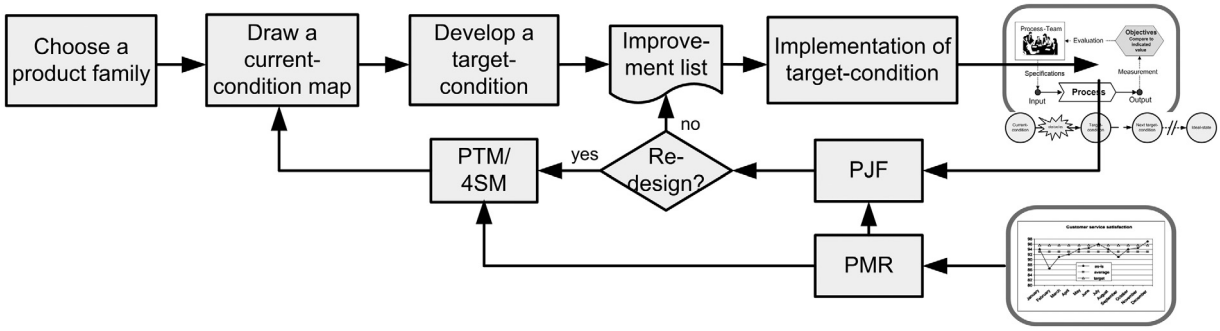

Figure 3. Enhanced 4-Step-Method of the Value Stream oriented Process Management (Kuhlang et al. 2013, 12).

5. VSM and MTM

The combined application of VSM and MTM is increasing productivity and raising the added value of a company. Supplementary targets are the reduction of lead time and therefore of inventory enabled by VSM and the standardisation of processes and a solid time determination based on an international performance level – MTM's norm performance. MTM is the abbreviation for MTM, meaning that the time required to execute a particular activity depends on the method performed for this activity. It is a modern instrument to describe, structure, design and plan work systems applying defined process building blocks. MTM represents an internationally valid performance standard for manual tasks and modelling and designing human – in the sense of manual – work (Kuhlang et al. 2014; Kuhlang 2015).

A process building block represents a process step with defined work content and a distinct purpose for which a standard time applies. A system of process building blocks consists of a defined amount of process building blocks. The MTM system of process building blocks was developed for a specific, clearly defined process typology, a specific complexity of processes and defined process characteristics. MTM process building block systems are allocated to clearly defined fields of application such as mass production, batch production or job shop production. They provide a formal descriptive language for processes, are used uniformly throughout the world and are keen on recognising the relevant influencing factors in a process. (Bokranz and Landau 2012).

The application of VSM and MTM to increase the different dimensions of productivity (work method, performance, utilisation) provide a valuable and profound understanding of productivity whereas the work method plays the most important role (Whitmore 1987; Helmrich 2003; Sakamoto 2010).

The advantage of this mutual usage (Table 1) arises from an aligned design and improvement of work design and production-logistics aspects in work systems, their work methods and in the overall value stream. Both methodologies are contributing to identifying, assessing, reducing, eliminating and/or avoiding waste.

MTM is a tool based on a uniform process language to describe and standardise processes. In addition, it provides the time (influential working time t_{tb} as an element of the basic time t_g) of the single processes in the value stream. Through its solid time determination and with its systematic analysis of processes, MTM fosters productivity improvement. The focus of optimisation is the individual activities and work places (consideration of single processes).

MTM process building blocks provide several different information to a value stream, i.e. the operating time, detailed, chronological description of the work method, the amount of added value respectively the amount of identifiable waste. MTM process building blocks therefore improve quality in evaluating the flow degree (lead time divided by operating time). Figure 4 visualises where MTM may be applied in a value stream.

Once MTM has been successfully implemented in an organisation, VSM is a valuable extension in order to analyse the whole process chain. Conversely, if an organisation already uses VSM as a tool, the application of MTM is a useful addition. The following practical areas of application and possibilities for use result from the interplay of the combination of VSM and MTM (Figure 4):

- assessment of added value rates
- assessment of production-logistics processes
- ergonomic assessment of work systems
- current/target-condition comparison respectively current state map (CSM) / future state map (FSM) comparisons
- balancing
- layout design (overall and single level).

Table 1. Benefits of the joint application of VSM and MTM (Kuhlang, Edtmayr, and Sihn 2011).

	VSM	MTM
Exact determination and assessment of		
• operating, transport and set-up times		X
• performance and utilisation		X
Reduction of lead time through		
• minimising and eliminating idle times	X	
• improvement and redesign of methods and reducing in operating and transport times	X	X
Increase in productivity through		
• design of methods	X	
o flow-oriented consideration (overall processes)		X
o task-oriented consideration (single processes)		X
• improvement in performance and utilisation		X
• standardising processes		
Reduction of inventory in form of	X	
• raw materials, work in progress and finished goods		
Improvement in delivery reliability through	X	
• reduction of lead time		
• reduction of batch sizes		
• smoothing out fluctuations		
Evaluation and planning of flow of material		X
• based on standardised logistics process building blocs		
Reduction in control overhead through	X	
• simplification of information flow		
• application of the principles of self-regulation (supermarket,...)		
Reduction in required shop floor areas through		
• material flow optimisation improved workplace layout	X	
• improved workplace design		X
• lower stock quantities (inventory)	X	
Comparability and evaluation of current-conditions and target-conditions		X
• internationally applied, standard performance benchmarks for human work		
Simulation capability	X	X
• planning, design, assessment and optimisation of ‘virtual’ methods (flow- and task-oriented) in current-conditions and target-conditions		
Comprehensible documentation of methods	X	X
• simple and easily understood documentation of the processes and work procedures		
• transferability of results		

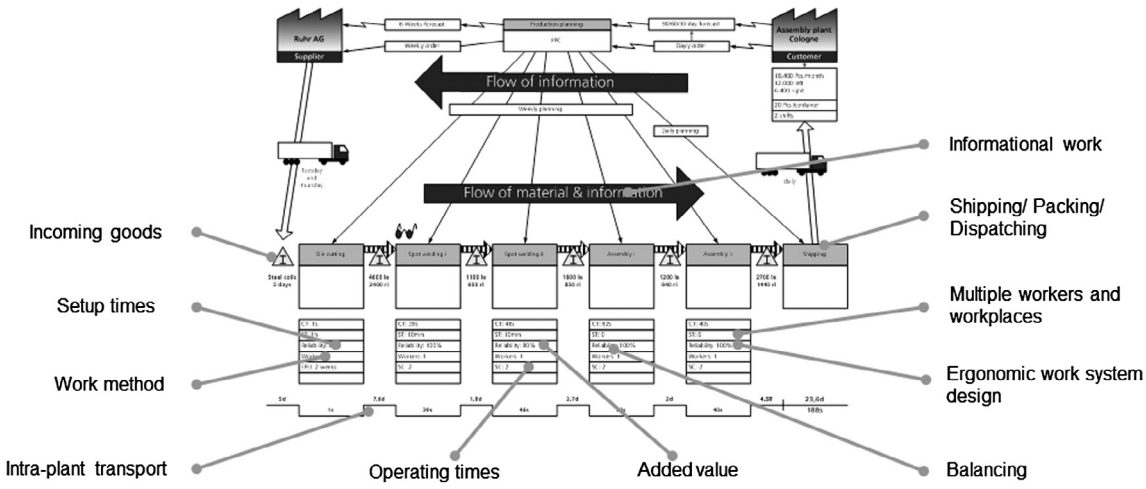

Figure 4. Options to apply MTM in a value stream (Kuhlang, Edtmayr, and Sihn 2011, 26).

6. Sustainable VSM

SVSM is an approach for process-oriented accounting of resource consumption combined in value streams. The modelling enables a value stream manager calculating sustainability indicators to immerse into improving resource efficiency when improving value streams. This approach is initially based on a specific VSM tool called Quality Filter Mapping. There, product defects, service defects and especially internal defects together as one part of seven wastes (= defects) in lean manufacturing are discussed (Hines and Rich 1997). Additional aspects and modelling approaches for cumulated scrap rates and scrap costs were published (Sullivan, McDonald, and Van Aken 2002; Amin and Karim 2011; Haefner et al. 2014), providing the basis of the following model-based approach for sustainable VSM. The additional inclusion of sustainability in lean can be seen as a development of the traditional short-term (e.g. yearly base) perspective. This combination of lean manufacturing and sustainable development is documented to increase quality, customer satisfaction, decreasing costs and reducing lead time (Nitin, Deshmukh, and Suresh 2010). The practical application of lean principles and scientific discussion became very popular, indicated through the rising number of published papers about lean management and sustainability (Martínez-Jurado and Moyano-Fuentes 2013). But, several studies indicate that lean practices do not necessarily improve environmental performance (Venkat and Wakeland 2006; Yang et al. 2010).

Several approaches found in scientific literature (Simons and Mason 2002; Erlach and Westkämper 2009; Torres and Gati 2009; Kuriger and Chen 2010; Paju et al. 2010; Kuriger, Huang, and Chen 2011; Dadashzadeh and Wharton 2012; Faulkner and Badurdeen 2013) and online (United States Environmental Protection Agency 2014) somehow deal with sustainability in value streams – but only very superficially and without detailed consideration of resource use and cycle and especially without an underlying, universal model for the calculation of sustainability indicators. Therefore, we established an approach (Edtmayr, Sunk, and Sihn, forthcoming) to assess the creation of waste in value streams within a consistent model. It suits to the European Waste Framework Directive (European Commission 2015) which defines the steps from raw material to disposal including reuse, recycle and recovery. Figure 5 shows the principle of virtual layers of the ideal-reutilisation cycle for each process in the value stream.

Each process of a value stream gets virtual layers for the re-utilisation categories reuse, recycle, recovery and disposal. One specific reutilisation cycle then consists of five transport activities, three buffers and the reutilisation process itself to become an ideal-typical re-utilisation cycle. This ideal-typical reutilisation cycle is applicable for all kinds of production/assembling processes. In practice, the necessary input parameters are way less than the ideal-typical reutilisation cycle offers.

6.1 *Modelling the creation of waste in VSM*

The first published sustainability issue to be modelled is the creation of material waste in the process chain. The sum of waste per observation or time period – e.g. day – is calculated as follows:

$$W = W_{\text{nok}} + W_{\text{ok}} + W_{\text{set-up}} \tag{1}$$

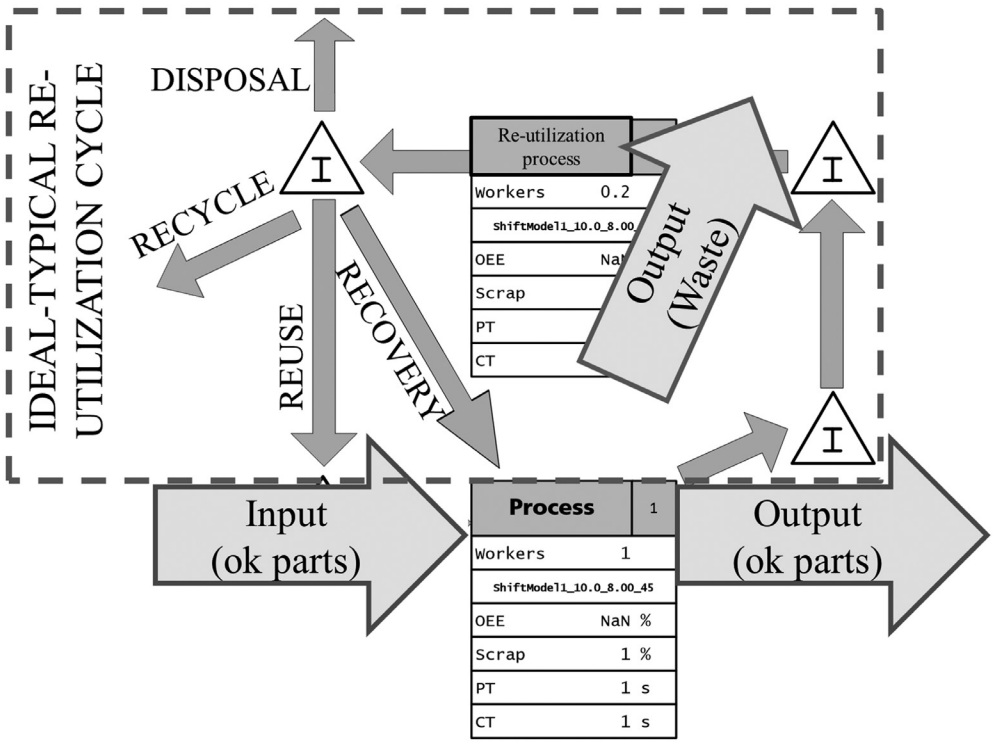

Figure 5. Principle of an ideal-typical reutilisation cycle (Edtmayr, Sunk, and Sihn, forthcoming).

- W … total waste [kg per time period]
- W_{nok} … waste due to cum. scrap rate [kg per time period]
- W_{ok} … waste due to material input difference [kg per time period]
- $W_{\text{set-up}}$ … waste due to set-ups [kg per time period]

To convert the waste per unit the calculated waste per time period must be divided by the number of parts produced. Thus, the waste per part $w_{(i)}$ for each process i is:

$$w(i) = \frac{d_g(i)}{1 - s_{\text{cum}}(i)} - d_n(i) + \frac{W_b(i)}{b(i)} \tag{2}$$

- $w_{(i)}$ … total waste per ok part [kg per ok part]
- d_g … gross weight of input resource [kg per part]
- s_{cum} … cumulated scrap rate [%]
- d_n … net weight of input resource [kg per part]
- W_b … waste per batch [kg per batch]
- b … batch size [parts per batch]

The waste per part can be calculated for each process and each resource which is used.

6.2 *Use case: creation of waste in value streams*

Our use case is based on site visits to illustrate is from in automotive industry presented in a neutral form. Our value stream consists of four serial process with technologies injection moulding, painting, assembly and sequencing/shipping. All gross and net demands of resources in [kg/part] in processes are known because of bill of materials. Average values for batch sizes, scrap rates and wastes per batches are also known. Following the calculations above, the waste created for each process step and each type of resource can be calculated. Looking at injection moulding process in specific, gross demand of material is 3.85 [kg/part] and net demand is 3.65 [kg/part]. Hence, 0.20 [kg/part] of waste each

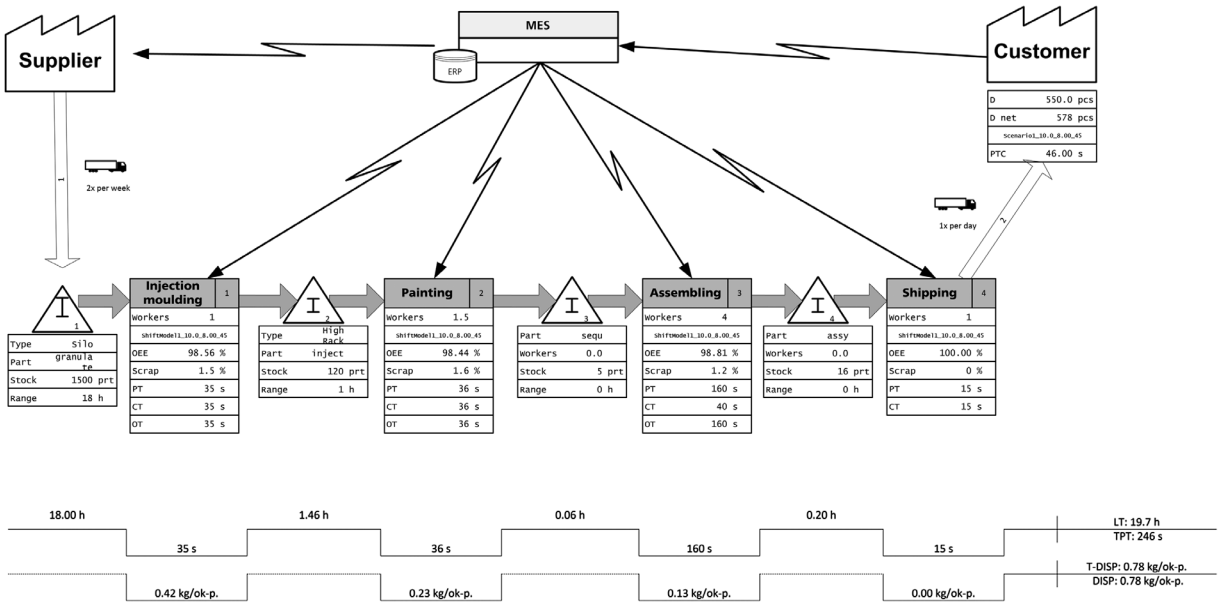

Figure 6. Disposals data line in VSM.

production cycle is created. Usually, every 300 parts process gets a setup for new variant and therefore the rest of material in intake pipe needs to be thrown away. In our case, it is 13 [kg/batch]. Furthermore, each process has a specific scrap rate and so upstream processes need to produce more goods than customer demand is in average. The negative effects of scrap rates are 'multiplied' upstream, so in our case the cumulated scrap rate is 4.24 [%]. Typing in the numbers in the calculation, 0.42 [kg/part] waste gets created. Afterwards, one can assign the total scrap to the reutilisation categories, e.g. 100% disposals or 80% disposals and 20% recycle. The value stream planner gets new means to assess wastes not only in sense of lean but also in sustainability management, also monetary due to elements of reutilisation cycle. Figure 5 shows a possible new data line in VSM accordingly to logistics, space and traditional lead time (Figure 6).

Finally, the contributions of our presented further developments of VSM to enhance system and methods competence of individuals as well as organisations are described.

7. Contributions of further developments to system and methods competence

An important consideration to enhance system and methods competencies can be found in the fact that known and proven methods from a variety of disciplines and areas of a company have to be brought together. Thus, implicit personal and organisational knowledge of the acting employees is made available and the cognitive capability of a social entity (collective intelligence) is increased. By concentrating competencies systematically along the value stream, they are available to support rationalisation attempts in an appropriate application-oriented way. System and methods competence are addressed through the model of Value Stream-oriented Process Management by imbedding VSM and a short-cyclic improvement routine into the organisational framework of Process Management to support a systematic improvement of value streams in different observation levels and degrees of details methodically. Similarly, these competencies are enhanced by a systematic immersion of the VSM with MTM, since a coordinated design and an improvement of work design and (production) logistical aspects in work systems and their work methods as well as along an entire value stream takes place. SVSM provides a detailed analysis of (material) resource flows and consumptions in process chains with the presented metrics and therefore a basis for understanding 'where' and 'why' resource waste occurs. This leads to an increase of methods and system competence for both individuals and organisations. Table 2 shows the contributions of the presented further developments of VSM to system competence and Table 3 to methods competence.

Table 2. Contributions to system competence.

	System competence
Value Stream oriented Process Management	• Total view of the higher-levelled process landscape down to operational processes – expansion of VSM as a methodology of comprehensive value stream and process analysis • Embedding into the comprehensive view of process management with regard to the consideration of company objectives (strategic, tactical) and customer requirements while improving processes • Presentation of problems and improvements in a value stream and directly in its processes – analysis of dependencies and interactions
VSM and MTM	• Design of the different dimension of productivity (work methods, performance, utilisation) • Presentation of problems and improvements in a value stream in directly in its processes – analysis of dependencies and interactions • Standardisation of work methods and application of an international performance standard for human work • Flow and activity-oriented view for analysing material, capacity and time buffers. • Specification of target-conditions and ideal-states by VSM and MTM • Identification and prioritisation of productivity and rationalisation improvement potentials
SVSM	• The proposed model enables to integrate sustainability management into VSM with a consistent model • The process-oriented accounting of resource consumption combined with VSM to calculate sustainability indicators enables a value stream manager to understand the causes of waste creation in linked processes as well as the effects on costs per product produced • The ideal-typical re-utilisation cycle in a value stream enables a detailed view of (material) resource waste (= muda) of complex production systems – for each processes as well as for the whole value stream in the form of a disposal data line

Table 3. Contributions to methods competence.

	Methods competence
Value Stream oriented Process Management	• Total view of the higher-levelled process landscape down to operational processes – expansion of VSM as a methodology of comprehensive value stream and process analysis. • Embedding into the comprehensive view of Process Management with regard to the consideration of company objectives (strategic, tactical) and customer requirements while improving processes. • Presentation of problems and improvements in a value stream and directly in its processes – analysis of dependencies and interactions. • Systematic, long- and short-cyclic improvement of value streams towards the ideal-state.
VSM and MTM	• Methodology to apply VSM together with MTM; Application conditions are defined. • Reduction of inventory, minimising the processing time, increase productivity based on established designed work methods. • Standardisation of processes and exact time determination based on an international performance standard for human work.
SVSM	• The process-oriented accounting of resource consumption combined with VSM to calculate sustainability indicators enables a value stream manager to immerse into improving resource efficiency in value streams with use of lean principles. • The ideal-typical re-utilisation cycle as a means to evaluate (material) resource waste (= muda) both quantitative and monetary enables a value stream manager to assess waste on ecological sustainability consistent and standardised.

8. Summary and outlook

This paper presents the identification of System Competencies and Method Competencies in findings of specific VSM publications. In specific, published developments of traditional VSM demonstrate the enhancement of both System Competence and Methods Competence of organisations as well as individuals. In particular, publications regarding (a) 'Value Stream oriented Process Management' which integrates VSM into the management of the PLC); (b) the immersion of VSM by the systematic combination with MTM to evaluate work methods at processes, buffers and transports; and (c) including several aspects of Sustainability Management into VSM (i.e. a waste accounting approach) are described. In fact, scientific contributions of us and other authors to further develop traditional VSM are used in this paper as the fundament to enhance System Competence and Methods Competence of both organisations and individuals. Examples are given in the following sections.

On the one hand these statements show, how practical approaches respectively rationalisation concepts are applied in industry (Process Management, VSM, short-cyclic improvement routine, MTM) are combined in order to manage and improve processes and value streams.

The portfolio of applicable lean methods to support rationalisation attempts is extended. The further developments of VSM focus on the entire flow and on details, thus creating synergies for designing and improving value streams, processes and work systems. In production research, they provide approaches to raise productivity, reduce lead time and approaches to evaluate value stream comprehensively. Due to these further developments, decentralised existing implicit knowledge is made explicated in different areas of a company. Known and proven methodologies from different disciplines and areas of a company are brought together and bundled along the value stream.

Thus, the personal and organisational system and methods competencies are applied to assess improvement procedures and support their implementation target-oriented. The collective intelligence of a company enhances, since these competencies are made transparent, combined, adapted, reinterpreted and further developed. Therefore, systematic and methodical planning, target-oriented design, implementation and rationalisation as well as sustainable improvement of processes respectively value streams is facilitated.

The gathered positive experiences with these extensions and immersions of VSM and the realised rationalisations lead to further developments, e.g. the ergonomics and maintenance value stream, an immersion with work and time study methodologies and the application of the VSM in the early phases of product emergence.

Disclosure statement

There is no conflict of interest for the authors of this paper, because none of them has a financial, commercial, legal or professional relationship with an organisation that may or had influenced this research.

References

Abdulmalek, F. A., and J. Rajgopal. 2007. "Analyzing the Benefits of Lean Manufacturing and Value Stream Mapping via Simulation: A Process Sector Case Study." *International Journal of Production Economics* 107 (1): 223–236.

Amin, M. A., and M. A. Karim. 2011. "A Systematic Approach to Evaluate the Process Improvement in Lean Manufacturing Organizations." In *Sustainable Manufacturing*, edited by G. Seliger, 65–70. Berlin: Springer.

Ballé, M. 2012. "The Lean Edge." Accessed October 8, 2015. http://theleanedge.org/?p=3875

Bertolini, M., M. Braglia, G. Romagnoli, and F. Zammori. 2013. "Extending Value Stream Mapping: The Synchro-MRP Case." *International Journal of Production Research* 51 (18): 5499–5519.

Bhamu, J., A. Khandelwal, and K. S. Sangwan. 2013. "Lean Manufacturing Implementation in an Automated Production Line: A Case Study." *International Journal of Services and Operations Management* 15 (4): 411–429.

Bokranz, R., and K. Landau. 2012. *Handbuch Industrial Engineering: Produktivitätsmanagement mit MTM. Band 1 Konzept*. Stuttgart: Schäffer-Poeschel Verlag.

Chen, J. C., Y. Li, and B. D. Shady. 2010. "From Value Stream Mapping Toward a Lean/Sigma Continuous Improvement Process: An Industrial Case Study." *International Journal of Production Research* 48 (4): 1069–1086.

Dadashzadeh, M., and T. Wharton. 2012. "A Value Stream Approach for Greening the IT Department." *International Journal of Management & Information Systems* 16 (2): 125–136.

Dal Forno, A. J., F. A. Pereira, F. A. Forcellini, and L. M. Kipper. 2014. "Value Stream Mapping: A Study about the Problems and Challenges Found in the Literature from the past 15 Years about Application of Lean Tools." *The International Journal of Advanced Manufacturing Technology* 72: 779–790. doi:10.1007/s00170-014-5712-z.

Deuse, J., M. Rother, and S. Hempen. 2009. "Managing Continuous Innovation in a Manufacturing Environment." Paper presented at the 10th International Continuous Innovation Network (CINet) Conference, Brisbane, September 4–8.

Edtmayr, T., A. Sunk, and W. Sihn. Forthcoming. "An Approach to Integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping." In *Procedia CIRP*. Elsevier.

Edwards, J. N. 1983. "MRP and Kanban-American Style." In *American Production & Inventory Control Society: APICS 26th Annual Conference Proceedings*, New Orleans, LA. 586–603.

Erlach, K. 2007. *Wertstromdesign: Der Weg zur schlanken Fabrik* [Value Stream Mapping: The Road to a Lean Factory]. Berlin: Springer-Verlag.

Erlach, K., and E. Westkämper. 2009. *Energiewertstrom – Der Weg zur energieeffizienten Fabrik* [Energy Value Stream – The Road to an Energy-efficient Factory]. Stuttgart: Fraunhofer Verlag.

European Commission. 2015. "Directive 2008/98/EC on Waste (Waste Framework Directive)." Accessed October 8, 2015. http://ec.europa.eu/environment/waste/framework/index.htm

Faulkner, W., and F. Badurdeen. 2013. "Sustainable Value Stream Mapping (Sus-VSM): Methodology to Visualize and Assess Manufacturing Sustainability Performance." *Journal of Cleaner Production* 85: 8–18.

Green, J. C., J. Lee, and T. A. Kozman. 2010. "Managing Lean Manufacturing in Material Handling Operations." *International Journal of Production Research* 48 (10): 2975–2993.

Haefner, B., A. Kraemer, T. Stauss, and G. Lanza. 2014. "Quality Value Stream Mapping." *Procedia CIRP* 17: 254–259. doi:10.1016/j.procir.2014.01.093.

Helmrich, K. 2003. *Productivity Processes: Methods and Experiences of Measuring and Improving*. Stockholm: Informgruppens Förlag.

Hevner, A. R., S. T. March, J. Park, and S. Ram. 2004. "Design Science in Information Research." *MIS Quarterly* 28 (1): 75–105.

Heyse, V., J. Erpenbeck, and S. Ortmann. 2010. "Kompetenzen: Eine begriffliche Klärung." In *Die Kompetenzbiographie: Wege der Kompetenzentwicklung*, edited by J. Erpenbeck. 13–19. Münster: Waxmann Verlag.

Hines, P., and N. Rich. 1997. "The Seven Value Stream Mapping Tools." *International Journal of Operations & Production Management* 17: 46–64. doi:10.1108/01443579710157989.

Hopp, W. J., and M. L. Spearman. 2008. *Factory Physics*. 3rd ed. New York: McGraw-Hill.

Imai, M. 1986. *Kaizen: The Key to Japan's Competitive Success*. New York: Random House.

Ishii, K. 2013. "A Production Research to Create New Value of Business Output." *International Journal of Production Research* 51 (23–24): 7313–7328.

Klevers, T. 2007. *Wertstrom-Mapping und Wertstrom-Design: Verschwendung vermeiden – Wertschöpfung steigern* [Value Stream Mapping and Value Stream Design: Avoid Muda – Increase Added Value]. Landsberg am Lech: mi-Fachverl., Redline.

Kuhlang, P. 2012. *Industrial Engineering: Systematische Gestaltung produktiver, industrieller Wertströme* [Industrial Engineering: Systematic Design of Productive, Industrial Value Streams]. Habilitation: Vienna University of Technology.

Kuhlang, P. 2015. *Modellierung menschlicher Arbeit im Industrial Engineering – Grundlagen, Praxiserfahrungen und Perspektiven* [Modelling Human Work in Industrial Engineering – Fundamentals, Practical Applications and Perspectives]. Stuttgart: Ergonomia.

Kuhlang, P., T. Edtmayr, and W. Sihn. 2011. "Methodical Approach to Increase Productivity and Reduce Lead Time in Assembly and Production-logistic Processes." *CIRP Journal of Manufacturing Science and Technology* 4 (1): 24–32.

Kuhlang, P., S. Hempen, W. Sihn, and J. Deuse. 2013. "Systematic Improvement of Value Streams – Fundamentals of Value Stream Oriented Process Management." *International Journal of Productivity and Quality Management* 12 (1): 1–17.

Kuhlang, P., O. Erohin, M. Krebs, J. Deuse, and W. Sihn. 2014. "Morphology of Time Data Management – Systematic Design of Time Data Management Processes as Fundamental Challenge in Industrial Engineering." *International Journal of Industrial and Systems Engineering* 16 (4): 415–423.

Kurdve, M., S. Shahbazi, M. Wendin, C. Bengtsson, and M. Wiktorsson. 2014. "Waste Flow Mapping to Improve Sustainability of Waste Management: A Case Study Approach." *Journal of Cleaner Production* 98 (1): 1–12.

Kuriger, G., and F. Chen. 2010. "Lean and Green: A Current State View." *Industrial Engineering Research Conference*. Cancun, Mexico.

Kuriger, G., Y. Huang, and F. Chen. 2011. "A Lean Sustainable Production Assessment Tool." *Proceedings of the 44th CIRP Conference on Manufacturing Systems*. Madison, WI.

Li, J. 2013. "Continuous Improvement at Toyota Manufacturing Plant: Applications of Production Systems Engineering Methods." *International Journal of Production Research* 51 (23–24): 7235–7249.

Lian, Y.-H., and H. Van Landeghem. 2007. "Analysing the Effects of Lean Manufacturing Using a Value Stream Mapping-Based Simulation Generator." *International Journal of Production Research* 45 (13): 3037–3058.

Liker, J. K. 2009. *Der Toyota-Weg: 14 Managementprinzipien des weltweit erfolgreichsten Automobilkonzerns* [The Toyota Way: 14 Management Principles of the Gobal Successful Automotive Group]. 6th ed. München: FinanzBuch-Verlag.

Liker, J. K., and D. Meier. 2006. *The Toyota Way Fieldbook: A Practical Guide for Implementing Toyota's 4Ps*. New York: McGraw-Hill.

Lourenço, E., A. Baptista, and J. P. Pereira. 2013. "Multi-layer Stream Mapping: A New Approach to Assess Production System's Overall Efficiency & Eco-efficiency." *Proceedings of the 20th CIRP International Conference on Life Cycle Engineering*. Singapore.

Mahfouz, A., J. Crowe, and A. Arisha. 2011. "Integrating Current State and Future State Value Stream Mapping with Discrete Event Simulation: A Lean Distribution Case Study." In *Proceedings of Int. Conf. on Advances in System Simulation*, Barcelona, Spain. 161–168.

Marangoni, G., G. Romagnoli, and F. Zammori. 2013. "Multiple Value Stream Mapping : How to Implement Work Load Control in Complex Systems." *IESM'2013, International Conference on Industrial Engineering and Systems Management*. Rabat, Morocco.

Marin-Garcia, J., M. Pardo, and T. B. Martín. 2008. "Longitudinal Study of the Results of Continuous Improvement in an Industrial Company." *Team Performance Management* 14 (1): 56–69.

Martínez-Jurado, P. J., and J. Moyano-Fuentes. 2013. "Lean Management, Supply Chain Management and Sustainability: A Literature Review." *Journal of Cleaner Production* 85: 134–150.

Nitin, U., S. G. Deshmukh, and G. Suresh. 2010. "Lean Manufacturing for Sustainable Development." *Global Business and Management Research: An International Journal* 2 (1): 125–137.

O'Brien, C. 2013. "Fifty Years of Shifting Paradigms." *International Journal of Production Research* 51 (23–24): 6740–6745.

Ohno, T. (1998). *Toyota Production System Beyond Large-scale Production*. Portland, OR: Productivity Press – after Ohno, T. (1998). *Toyota seisan höshiki*. Tokyo, Japan: Diamand.

Paju, M., J. Heilala, M. Hentula, A. Heikkila, B. Johansson, S. K. Leong, and K. W. Lyons. 2010. "Framework and Indicators for a Sustainable Manufacturing Mapping Methodology." *Proceedings of the 2010 Winter Simulations Conference*. Baltimore, MD.

Peffers, K., T. Tuunanen, M. A. Rothenberger, and S. Chatterjee. 2007. "A Design Science Research Methodology for Information Systems Research." *Journal of Management and Information Systems.* 24: 45–77. http://doi:10.2753/MIS0742-1222240302.

Pettersen, J. 2009. "Defining Lean Production: Some Conceptual and Practical Issues." *The TQM Journal* 21 (2): 127–142.

Povey, B. 1996. *Continuous Business Improvement: Linking the Key Improvement Processes for Your Critical Long-term Success*. London: McGraw-Hill.

Remenyi, C., and S. Staudacher. 2014. "Systematic Simulation Based Approach for the Identification and Implementation of a Scheduling Rule in the Air Craft Engine Maintenance." *International Journal of Production Economics* 147 (1): 94–107. http://dx.doi.org/10.1016/j.ijpe.2012.10.022.

Richter, R., and J. Deuse. 2011. "Industrial Engineering im modernen Produktionsbetrieb: Voraussetzung für einen erfolgreichen Verbesserungsprozess [Industrial Engineering in Modern Production Faciltites: Preconditions for a Successful Improvement Process]." *Betriebspraxis & Arbeitsforschung* 207: 6–13.

Roosen, T. J., and D. J. Pons. 2013. "Environmentally Lean Production: The Development and Incorporation of an Environmental Impact Index into Value Stream Mapping." *Journal of Industrial Engineering* 2013: 1–17. Accessed February 2, 2014. http://www.hindawi.com/journals/jie/2013/298103/

Rother, M. 2009. *Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results*. New York: McGraw Hill.

Rother, M., and J. Shook. 2006. *Learning to See: Value-stream Mapping to Create Value and Eliminate Muda*. Cambridge, MA: Lean Enterprise Institute.

Sakamoto, S. 2010. *Beyond World-class Productivity: Industrial Engineering Practice and Theory*. London: Springer-Verlag.

Saleeshya, P. G., and P. Raghuram. 2012. "Lean Manufacturing Practices in Textile Industries – A Case Study." *International Journal of Collaborative Enterprise* 3 (1): 18–37.

Schultetus, W. 2001. "Arbeitsstandards: Anforderungen und Notwendigkeiten [Work Standards: Requirements and Necesseties]." In *Arbeitsschutz – Ergonomie – Normleistung: Strategische Beiträge zur ganzheitlichen Arbeitsgestaltung* [Work Safety – Ergonomics – Standard Performance: Strategies for an Holistics Work Design]. Dortmund: Wirtschaftsverlag NW.

Seyedhosseini, S. M., A. E. Taleghani, A. Makui, and S. M. Ghoreyshi. 2013. "Fuzzy Value Stream Mapping in Multiple Production Streams: A Case Study in a Parts Manufacturing Company." *International Journal of Management Science and Engineering Management* 8 (1): 56–66.

Simons, D., and R. Mason. 2002. "Environmental and Transport Supply Chain Evaluation with Sustainable Value Stream Mapping." Paper presented at the 7th Logistics Research Network Conference, Birmingham.

Singh, B., and S. K. Sharma. 2009. "Value Stream Mapping as a Versatile Tool for Lean Implementation: An Indian Case Study of a Manufacturing Firm." *Measuring Business Excellence* 13 (3): 58–68.

Solding, P., and P. Gullander. 2009. "Concepts for Simulation Based Value Stream Mapping." In *IEEE Proceedings of the 2009 Winter Simulation Conference*, Austin, TX. 2231–2237.

Spear, S. 1999. *The Toyota Production System: An Example of Managing Complex Social/Technical Systems*. Boston, MA: George F. Baker Foundation, Harvard University.

Spear, S., and H. K. Bowen. 1999. "Decoding the DNA of the Toyota Production System." *Harvard Business Review* 77: 97–106.

Steffen, M. 2010. "Ermittlung der erforderlichen Kompetenzen im Industrial Engineering zur systematischen Durchführung von Verbesserungsmaßnahmen in der Produktion." Thesis, TU Dortmund University.

Sullivan, W. G., T. N. McDonald, and E. M. Van Aken. 2002. "Equipment Replacement Decisions and Lean Manufacturing." *Robotics and Computer-Integrated Manufacturing* 18: 255–265.

Takeda, H. 2009. *Das synchrone Produktionssystem: Just-in-Time für das ganze Unternehmen* [The Synchronized Production System: Just-in-Time for the Whole Company]. 6th ed. München: mi-Wirtschaftsverlag.

Torres, A. S., and A. M. Gati. 2009. "Environmental Value Stream Mapping (EVSM) as Sustainability Management Tool." Paper presented at the Management of Engineering & Technology, PICMET 2009. Portland International Conference, Portland, OR, August 2–6. IEEE.

United States Environmental Protection Agency. 2014. "The Lean, Energy and Climate Toolkit." Accessed November 11, 2014. http://www.epa.gov/lean/environment/toolkits/energy/index.htm

Venkat, K., and W. Wakeland. 2006. "Is Lean Necessarily Green?" *Proceedings of the 50th Annual Meeting of the ISSS – 2006*. Sonoma, CA, USA, North America, Juni. Accessed October 19, 2015. http://journals.isss.org/index.php/proceedings50th/article/view/284/67

Villarreal, B. 2012. "The Transportation Value Stream Map (TVSM)." *European Journal of Industrial Engineering* 6 (2): 216–233.

Vinodh, S., K. R. Arvind, and M. Somanaathan. 2010. "Application of Value Stream Mapping in an Indian Camshaft Manufacturing Organization." *Journal of Manufacturing Technology Management* 21 (7): 888–900.

Wagner, K., and G. Patzak. 2007. *Performance Excellence*. Wien: Carl Hanser Verlag München.

Whitmore, D. A. 1987. *Work Measurement*. 2nd ed. München: Butterworth-Heinemann.

Xie, Y., and Q. Peng. 2012. "Integration of Value Stream Mapping and Agent-based Modeling for Operating Room Improvement." *Business Process Management Journal* 18 (4): 585–599.

Yang, T., and J.-C. Lu. 2011. "The Use of a Multiple Attribute Decision-making Method and Value Stream Mapping in Solving the Pacemaker Location Problem." *International Journal of Production Research* 49 (10): 2793–2817.

Yang, C., S. Lin, Y. Chan, and C. Sheu. 2010. "Mediated Effect of Environmental Management on Manufacturing Competitiveness: An Empirical Study." *International Journal of Production Economics* 123 (1): 210–220.