Michael Schabacker · Kilian Gericke
Nikoletta Szélig · Sándor Vajna *Editors*

Modelling and Management of Engineering Processes

Proceedings of the 3rd International Conference 2013

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Preface

Dear friends and colleagues,

as we know, Engineering processes have always been the glue that holds together all activities within product development and design. Engineering processes structure these activities appropriately and secure their reasonable processing. They ensure the correct and timely use of appropriate approaches & procedures, methods, data, and tools in order to improve the design procedures, improve products and services, and properly document both the resulting product as well as its development processes. It has been both the aim of the SIG MMEP (Modelling and Management of Engineering Processes) and of its conferences to contribute to a smart and smooth definition, application, and navigation of Engineering Processes.

I founded the SIG MMEP in 2003 based on discussions at different ICEDs, Rigi meetings, and IPD Workshops that clearly showed the necessity of consolidating the definition, the prospect, and the handling of processes in our Engineering environment. At ICED 07 in Paris I was pleased that John Clarkson agreed to share the SIG leadership with me in order to compare and to put together different approaches of managing Engineering processes and projects in turbulent environments, on which both our institutions have had a long and successful research history. We were lucky that Peter Heisig could be convinced to become a member of the team.

The MMEP conference series were launched in 2010 as a bi-annual event providing an international platform to highlight and to discuss industry best practices alongside leading edge academic research. The second MMEP conference in 2012 focussed on exploring potential synergies between different modelling approaches, and discussed future directions both in managing and researching engineering processes. The participants at MMEP 2012 decided to meet again at ICED 13 in Seoul and for the third MMEP conference in Magdeburg.

In 2013 we celebrated the 10th anniversary of our SIG. On behalf of my co-editors it was our pleasure organising the 3rd International Conference on MMEP 2013 at the Wasserburg (moated castle) of Gommern, close to Magdeburg, where it all started at the Otto-von-Guericke University. We hope that the participants enjoyed the conference. The papers chosen for this proceeding were selected by reference to blind reviews and discussions after their respective presentations undertaken by the participants. These papers represent the areas of process modelling, process optimisation, multi-project and process management, Key Performance Indicators, Lean Product Development and others. We would like to thank all those authors and reviewers who have contributed to the preparation of this book. We also thank Ms. E. Hestermann-Beyerle and Ms. B. Kollmar-Thoni from Springer for the smooth and constructive cooperation.

And, after ten years, it is a good practice to hand over the SIG leadership to younger people. I am very happy that Dr.-Ing. Kilian Gericke, University of Luxemburg, and Prof. Dr. Claudia Eckert, The Open University (UK), agreed to co-chair the SIG MMEP. Having known them well for a long time, I have no doubt that they will continue with the fruitful SIG work, of course (and hopefully!) with other aspects than we used to prefer in our time. But what will surely remain is that this our SIG will keep fascinating and challenging and beneficial to all its members.

Let me conclude. It was a highlight to work with you all! Good bye, and Vivat, Crescat, Floreat to our SIG on Modelling and Management of Engineering Processes!

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July 2014

Contents

Chapter 1

A Process Taxonomy Model for Engineering Design Research

N. Chucholowski, F. Schoettl, W. Bauer, S. A. Schenkl, F. Behncke and U. Lindemann

1.1 Introduction

Research on engineering processes plays a major role within engineering design research, since “the bulk of the effort involved in product development lies in perfecting the underlying processes” (Panchal *et al.*, 2004). Processes are getting even more important when considering the emerging research topic of product-service systems (PSS): PSS are an integration of product and service elements in one market offer (Baines *et al.*, 2007). Thereby not only design processes have to be considered but also the service product itself may be modeled as a process (Bullinger *et al.*, 2003).

There are many possible aspects to consider when doing research on engineering processes. Such process aspects comprise research on e.g. different processes among the product lifecycle (Panchal *et al.*, 2004), different activities on processes (Browning and Ramasesh, 2007), different process knowledge (Hubka and Eder, 1996), different characteristics of processes (Maier and Störrle, 2011) or the modeling of processes (Browning *et al.*, 2006). Research on engineering processes may compromise describing and modeling industrial processes, prescriptively defining processes as well as developing supporting methods and tools. The goals of these activities are amongst others to raise efficiency and effectiveness, resilience, adaptability or transparency of processes in the industrial practice.

Consequently, there is a big number of different research efforts and generated knowledge, which are hard to overlook. There are frameworks that attempt to order design knowledge respectively engineering design research efforts and findings, e.g. (Horváth, 2004). They are supposed to “help researchers to locate their work in the global picture of engineering design, […], granters to make decisions about the possible fields of investments, and educators to organize subject materials for various design courses” (Horváth, 2004). So far, process research is only a part of

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these frameworks and is addressed on a too rudimentary level to distinguish the above described aspects and the related research on these aspects.

We developed a taxonomy model that enables not only to regard specific types of processes in the product lifecycle and specific activities, which can be applied on these processes, but also the allocation of research efforts and results among these processes, activities and even the "research on research" on a meta-level. Furthermore, the transition of research into practice is addressed, which was identified as a lack of design research taxonomies by Fulcher (1998).

The process taxonomy for engineering processes as an explanatory model allows classifying, mapping and delimitating specific research activities and results. It considers the wholeness of aspects regarding the management and modeling of engineering processes.

1.2 Research Methodology

In order to get an integrated understanding of the topic as a foundation for the taxonomy model for engineering processes, we performed a literature review, considering publications on process research. The following keywords have been applied: design process, design process research, research model design process, engineering process research and process research. Besides that we have indexed 13 engineering process-related research projects funded from public organizations such as the German Research Foundation (DFG) as well as industry funded research projects. Based on that, we have prescriptively set up the taxonomy model considering relevant aspects of engineering processes on the two layers research and industry. For verification, we have discussed the model in a working group consisting of researchers working on different aspects of engineering design processes, such as product planning, engineering change management and production planning. Furthermore, the model was applied on several examples of process research to test its internal validity.

1.3 Process Research in Engineering Design Literature

This section gives a short overview of literature addressing design research in general, whereas the focus is on identified literature that deals with design process research. Afterwards, derived implications are described.

A look on literature about design research and design science reveals that the research on processes plays a major role (e.g. Fulcher, 1998; Horváth, 2004; Hubka and Eder, 1996; Panchal *et al.*, 2004; Pugh, 1990; Ullman, 1992). Most of their research efforts aim to classify and characterize research on design processes. A categorization of the process research space is necessary in order to identify appropriate tools and techniques for process research and to place research efforts in perspective (Ullman, 1992).

Amongst others but profoundly inspired by the technical systems theory (Hubka and Eder, 1996), Horváth (2004) categorized engineering design research in a framework. He considered process knowledge as one category within engineering design research; including the domains *design process*, *artifactual process* and *implicated process* (cf. Figure 1.1). Studying, modeling and the optimization of the design process itself are so called research trajectories within the domain *design process*. *Artifactual processes* address existential, operation, application and service processes of products. Research in the domain of *implicated processes* addresses all processes that are related to the realization and utilization of a product, e.g. technological, production, sales/supply and reclaiming processes (Horváth, 2004).

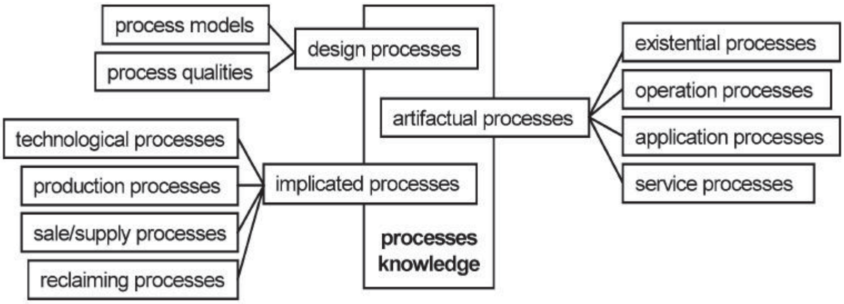

Figure 1.1. The domains and trajectories within the category "process knowledge" in the framework of reasoning by Horváth (2004)

The consideration of artifactual and implicated processes extends the perspective on design process research. Also Panchal *et al.* (2004) proclaim that design process research should integrate perspectives from the whole product lifecycle. When all lifecycle phases of a product are regarded during its design, the design process has to meet certain requirements. Based on this, Panchal *et al.* (2004) list the following research issues:

- modeling design processes;
- computational representations of design processes;
- storage of design information;
- developing metrics for assessing design processes;
- configuring design processes;
- integrated design of products and design processes;
- integrating design processes with other processes in product lifecycle management.

Hence the design process is not the only process that design research has to deal with. Designers have to consider all processes within the product life cycle.

For example, also the service process has to be designed when considering the design of product-service systems. As a lot of different processes have to be considered, it is hard to keep record which process is meant when speaking about engineering processes.

When looking at fundamental design literature (e.g. Hales and Gooch, 2004; Lindemann, 2009; Pahl *et al.*, 2007; Suh, 1990; Ulrich and Eppinger, 2003), chapters about the design process deal with the definition of the process itself, i.e.: What activities, methods, attributes are part of the process and what characteristics describe the process? Also more specific design process research (e.g. Clarkson and Eckert, 2005; Gericke and Blessing, 2011; Maier and Störrle, 2011) predominantly tends to define the process regarding different disciplines or process characteristics. Another often addressed issue in specific design process research is process modeling (cf. the literature review by Browning *et al.*, 2006).

No specific design process research literature was found which aims to categorize the complex and entangled topics and research issues of engineering processes. Process research concentrates on descriptive and prescriptive models that describe the design process. At the same time, research about the modeling of processes plays a major role. The development of taxonomies in order to categorize research areas happens predominantly within general design research. The taxonomies include the categorization of process research and consider issues such as the design processes itself (activities, characteristics, etc.) and process modeling. Additionally it becomes clear, that there are different types of relevant processes to investigate. A taxonomy is needed that enables to distinguish different processes on the one hand and different activities addressing these processes on the other hand.

1.4 A Taxonomy Model to Classify Engineering Design Process Research

In this section we explain the purpose of the model, describe its structure and individual parts as well as intended applications, and illustrate the use of the model.

1.4.1 Motivation and Intended Purpose of the Model

From a process research point of view, there is a need for support to classify research activities. By this, not only a classification in the present landscape of process research and a differentiation from other research projects is possible, but also research gaps can be identified. Potential users of the taxonomy model could be e.g. research institutions, researchers or design educators. Researchers and research institutions can create a profile of their research topics that is easy to understand and they can also identify and visualize future research fields that should be aimed at. For educators in the area of design the model can give a clear

overview on the different aspects that are relevant when dealing with engineering processes.
A significant added value compared to existing models is the level of abstraction of our approach, which allows an integrated and lifecycle-oriented consideration according to Systems Engineering. Specifically, these are the possible connections between research and practice, activities and considered processes in the product lifecycle as well as their interfaces, which is seen as particularly important (Fulcher, 1998).

1.4.2 Description of the Model

The described purposes result in the structure of our taxonomy model, which possesses three dimensions spanning a rectangular space (cf. Figure 1.2). The first axis *lifecycle processes* embodies several types of processes from the lifecycle phases of a system in order to classify all relevant processes used in mechanical design. The second axis *activities* in the basic layer shows major activities that are applied to a process. The third dimension allows to model an additional meta-level which regards research about the processes behind the activities and processes shown in the bottom layer. This level is necessary to be able to also classify e.g. research methodologies in process research. The combination of the three dimensions builds up our taxonomy model with 50 points in the defined space. For the classification of any kind of process-related activities, characteristics and the important interfaces in between, we have extended the points to cubes. On the one hand, that represents the steadiness and consistency of processes beyond lifecycle phases which is frequently the case in reality. On the other hand, the cubes facilitate a precise differentiation of several activities and processes along their edges or in their volume. Moreover research projects or activities with diverse practical relevance can be properly allocated in the model using different positions in the vertical dimension.

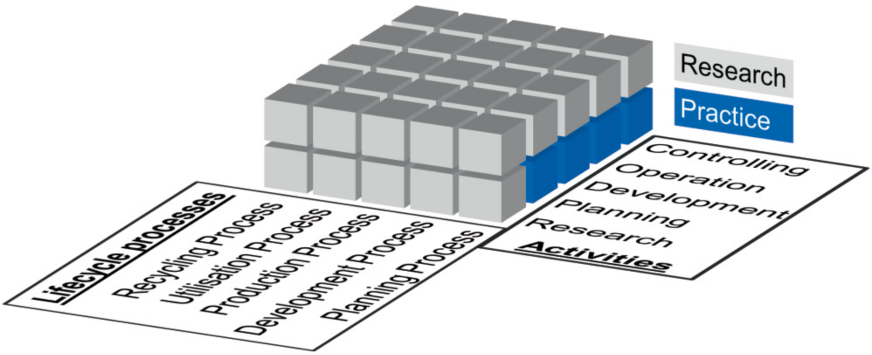

Figure 1.2. Taxonomy model for the classification of engineering process research issues

The processes that occur within the lifecycle of a system in one dimension can be summarized as product planning, development, production, utilization, and recycling process (Haskins and Forsberg, 2011; Hepperle *et al.*, 2009). Products, services or product-service systems can be subject of these processes and lifecycle phases. This axis determines what type of process is considered.

The other dimension is formed by activities that can be applied to the different lifecycle processes. Based on the process taxonomy by Ullman (1992) and the activities applied on processes listed by Browning and Ramasesh (2007), we selected four major activities for the classification: planning, development, operation and controlling. Considering design research, research can be applied to each of the listed system lifecycle processes. Therefore, the activity "research" is added to the second axes. The bottom layer, which is spanned by the two dimensions, maps "Activities on Processes". The process behind the activity "research on a lifecycle process" (e.g. research on development processes) is predominantly performed by academia. For this we chose grey colored cubes. The blue colored area can be interpreted as work with process issues in practice, such as the development of a production process, the planning of a development process or the controlling of a (product) planning process (predominantly performed by practitioners).

The last dimension complements the taxonomy model with research activities that are not represented in the bottom layer. It enables to classify also research, which is done on the activities that can be applied to processes. An example would be the "research on research on development processes". This means how to do research on development processes. Another example is the research on planning production processes, i.e. the "investigation of planning production processes" or how to plan production processes. Hence, the whole second layer and the research activity on the bottom layer incorporate process research in general.

The model also allows referring to interfaces between research and practice. The question of the transferability of research into practice e.g. in terms of controlling planning processes can be located at the transition between the corresponding gray and blue cube downwards. Basically, two different use cases according to the direction of transfer are conceivable. Bringing a scientifically developed method into practical application or transferring problems into a scientific context in order to find a solution with universal scope. Both use cases may include one or two interfaces between practice (blue) and research (grey) areas. The latter possibility is explained later in an example.

The application of the developed taxonomy model depends on the purpose and the user group. But the basic sequence for classifying research efforts or projects is the same:

1. Selection of the process(es) - Which process is considered?
2. Selection of activity/activities - What is being done with the concerning process?
3. Selection of a perspective - Is it about research, practice or a transfer?

After allocating process issues in the model, there are several possibilities to use the results. Since this depends on the specific use case and the perspective, we want to give some exemplary proposals. Researchers may allocate a project and find potential use cases for practical application of their results or for validating their approaches. Furthermore adjacent cubes show potential fields for future research. We strongly recommend to use the taxonomy model in its presented set-up without adding or removing elements, since we attempted to find the lowest common denominator in engineering process research. If there is a need for more detailed investigations, both axis (the lifecycle processes and the activities on processes) can be particularized. For example, the lifecycle process *development process* can be decomposed to more detailed process steps (e.g. concept design, detailed design, etc.) or the activity *controlling* can be split into measuring and adapting to gain a more detailed insight on the object of investigation. However, we recommend to not decompose the lifecycle processes and activities any further in order to keep the simplicity of the model as its strength.

1.4.3 Use Cases

The description and application of our taxonomy model is followed by an evaluation in this subsection. The focus is mainly on the model structure since the basic content of the three axes consists of commonly accepted knowledge in process research. The purposeful adjustment and the proper interplay of the dimensions are demonstrated in four examples, which represent different use cases according to the mentioned purpose.

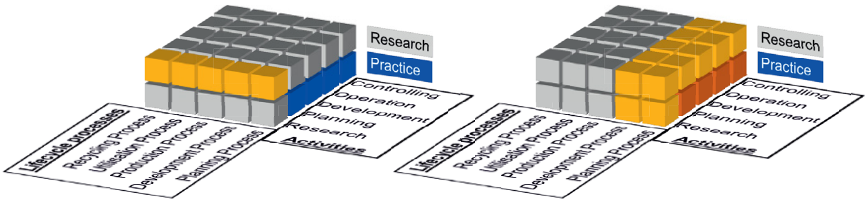

Figure 1.3. Allocation of a resarch methodology (l.) and a research institute (r.)

Figure 1.3 shows the allocation of a research methodology as well as a competence profile of a research institute. On the left side, the established design research methodology (DRM) (Blessing and Chakrabarti, 2009) is allocated to the five yellow cubes in the row of research activity in the upper layer of the model. DRM is research about research in design, with design considering all lifecycle phases of a system (i.e. product). Furthermore, this taxonomy model itself as contribution to process research fits into the same area as DRM because of its universal scope. On the right side, the competences of a research institute e.g. the Institute of Product Development at the Technical University of Munich are illustrated by the colored area. It covers activities like planning, developing, operating and controlling product planning processes or development processes in the context of industrial projects (orange). Research on these mentioned activities, research on the planning process and development process itself and finally research on research activities constitute the scientific part of the institute's competences (yellow).

To emphasize the single cubes and their interfaces, Figure 1.4 shows the allocation of a product development method and its transfer from research into practice. Some cubes were removed in this illustration to ensure a clear view on the relevant elements.

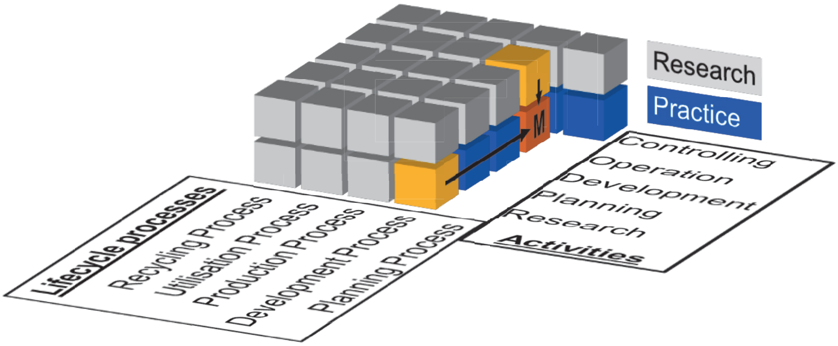

Figure 1.4. Allocation of a development method the transer into practice

The Munich Procedure Model („Münchner Vorgehensmodell“) by Lindemann (2009) serves as an example for a product development method, that can be understood as an instruction on the product development process. This method supports the operation of a product development process and consequently it is allocated in the orange cube labeled with “M”. Research on development processes and research on the operation of development processes are the scientific basis (yellow cubes). Both arrows represent the course of development to the final field of application.

1.5 Conclusion and Outlook

Taxonomies in design research are used to clarify and to simplify research topics (Fulcher, 1998). The presented process taxonomy model works as a descriptive taxonomy what enables to allocate research efforts in the global field of engineering processes (Horváth, 2004). As Fulcher (1998) stated, the often proposed two-dimensional or hierarchical taxonomies are unlikely to represent the various and complex research topics within engineering design in an adequate depth. By using three dimensions in this process taxonomy model, process research can be classified more precisely by indicating what kind of processes and what activities on the process are considered. Additionally, research on process definitions (characteristics, attributes, etc.), research on activities on processes, and research on research about processes can be differentiated. Besides the application by researchers and educators, the model also enables practitioners to border their competences and service portfolio against competitors as well as take strategic decisions based on the resulting transparency.

As mentioned earlier, specific research about the modeling of processes still draws the research agenda for both industry and academia due to its relevance.

Process models can be seen as tools used in every single cube in the taxonomy model. This implies, that the cubes could be more detailed regarding their content. In practice, there are process models for e.g. the development process as well as for the planning of development processes. Further, the modeling of these processes can be addressed in process research and it is always aligned with process attributes such as tasks, duration or performance indicators etc. Besides process modeling, requirements management, simulation, evaluation and other cross-cutting issues can also be seen as an artifact included in every cube in the taxonomy model.

Another conceivable differentiation of research efforts is to distinguish objects of research and research results. The allocation of a research project to one cube can have two intents: First, the process aligned to this cube is the object of investigation. Second, the results of the project have impact on the cube. For example, one can either look at production processes in order to optimize the product for this process (i.e. the process is object of the investigation) or the research investigates the product in order to develop an ideal production process (i.e. the research results regard the process). The differentiation of these aspects in the taxonomy model is still pending, so that its confirmation represents a first step of future research.

Moreover, the allocation of more examples or use cases is inevitable to ensure that all conceivable aspects of engineering design can be classified within the proposed taxonomy model. Furthermore, there is still a lack of experience where to allocate requirements and results of processes. Interfaces between the cubes have to be described in more detail, due to possible different input-output dependencies between processes and activities. They should also be modeled within the taxonomy model in order to emphasize their important role. Further, the reference to objects which are located in the center of the volume is unsatisfactory because they are hidden by others and therefore limits the usability of the presented taxonomy model. Moreover, the visualization needs further improvement in order to specify the object of the lifecycle processes and distinguish between products, services or PSS.

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Chapter 2

A Model for Value in Lean Product Development

G. I. Siyam, K. Gericke, D. C. Wynn and P. J. Clarkson

Lean product development has been developed and deployed in an effort to enhance company operations. Understanding value is the first step to becoming ‘Lean’. However, the mere translation of value from its conventional interpretation in lean production as ``something the customer will pay for`` does not equate to an effective value orientation in product development (PD). In order to better understand the theoretical context of PD value in research, as well as the potential application of a value orientation in practice, further study is necessary. This paper aims to broaden the understanding of PD value by discussing by linking roles in value creation and delivery to different contexts and phases of the product life cycle.

2.1 Motivation and Requirements

Product development processes have a critical impact in determining the success of an organisation. This is due to their consumption of approximately 75% of the organisation’s resources (Millard, 2001) and their role in materialising the product’s specifications (McManus, 2005). Therefore, various tools have been adopted to facilitate management and improvement of product development processes, such as the Design Structure Matrix (DSM) and lean value-oriented approaches. However, because of the complexity of product development and the high levels of uncertainty associated with it, these improvement efforts can be difficult (e.g. Pessoa, 2004). Moreover, available support (e.g. methodologies, methods, tools, recommendations and guidelines) are either very abstract, thus needing adaptation before application in a specific context, or they are very

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detailed and can only be applied in a particular situation (Gericke *et al*., 2013). This limits their application, or application may not provide the desired results

The success of value-oriented lean approaches at the operational level resulted in a wide range of literature aiming to apply these approaches and their potential improvements to product development (e.g. Millard, 2001, McManus, 2005). For example, one claimed improvement of value-oriented approaches is a 50-90% reduction in wasted time (McManus and Millard, 2002). Nevertheless, existing literature, proposing tools, techniques, and identifying lean principles, lacks a systematic representation and does not practically address the difference between manufacturing and product development (e.g. Browning, 2000). Furthermore, definitions of value in product development indicate aspects of ‘goodness’, such as flawless product, minimum cost and shortest schedule (e.g. (Slack, 1999), (Beauregard *et al*., 2008) and (Womack and Jones, 1996)), but often do not give explicit direction regarding how value can be added or measured in this specific context.

In order to broaden the understanding of value in lean product development, its dimensions, i.e. *definition*, *creation* and *delivery,* need to be further explored in a model that:

- relates the dimensions of value;
- helps to understand value dimensions in various contexts;
- considers the impact of different phases in the product life cycle.

These requirements for the model were identified from an analysis of literature of lean in product development. Each requirement will be discussed in greater detail in the following sections.

2.2 Models of Value in Lean Product Development

Research into value in lean product development is relatively young; few models to deepen the understanding of value have been proposed (see e.g. Chase (2001) and Browning (2003) for examples). Most of these models have in common an emphasis on one aspect of value, mainly its creation, but they do not provide sufficient examples to guide application in practice. For instance, Chase (2000) decomposes value into four key layers, which are: *perspective*, *entity*, *attribute*, and *metric*. The first layer is the value *perspective*, identifying to whom value is delivered, such as customer (end user), organization, and stakeholder (e.g. employees and shareholders). The second layer is the value *entity* which produces value for the system drivers (Browning *et al*., 2002), such as activity, information and resources. On the third layer, Chase odopted Slack’s proposed *attribute* for specifying value (Slack, 1999). Main attributes of value include: quality, time, cost and risk. On the fourth layer (*metric*), these attributes can be further analysed in terms such as meters and seconds. These metrics are suggested as performance measures for determining value level in product development processes (Slack, 1999).

A literature review (Siyam 2014) revealed that there is limited common ground to understand, manage and assess value. Therefore, a more holistic model to synthesise the results of the review, clarify the value delivery mechanism and to provide examples that guide application, is necessary. To meet this end, Siyam (2014) introduced an organising model, which will be adopted in this study and discussed in different contexts and phases in the product life cycle. The model aims to (1) synthesise the current understanding, management and assessment of value in lean product development, and (2) provide examples to guide application in practice.

2.3 Value Cycle Model

The Value Cycle Model defines three dimensions facilitating the understanding and improvement of value in lean product development. These dimensions are:

- definition,
- creation, and
- delivery.

The definition dimension determines 'what is considered valuable to whom?'. This includes the identification of stakeholders, such as user, internal customer and shareholders, and their perception of value. The creation dimension explores entities that add value and the mechanisms in which value is added. The main question tackled by this dimension is 'what creates value?'. Finally, the delivery dimension is concerned with measuring entities that carry value. The question here is 'how can value be measured?'.

Figure 2.1 provides an overview of the model. The model can be viewed as a cycle, in which value is added based on requirements set by the stakeholders in the 'definition' dimensions and are continuously assessed to ensure they satisfy the stakeholders. The cycle closes when value is delivered to the 'definition' dimension to confirm a successful value system. The three dimensions are related because a consensus on value understanding, its management and assessment must be reached. Each of the three dimensions is discussed in the next subsections.

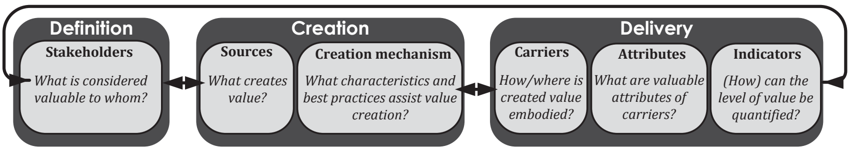

Figure 2.1. Overview of the Value Cycle Model (adopted from Siyam, 2014)