MATCHING PRODUCT ARCHITECTURE AND SUPPLY NETWORK - SYSTEMATIC REVIEW AND FUTURE RESEARCH

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Abstract

Manufacturing firms concentrate on their core competences to prevail in fierce competition. This concentration lead manufacturing firms to shift large shares of their value creation to their suppliers. As a result, the supply network drives the economic performance of manufacturing firms through three measures; individual performance of suppliers (1), their arrangement and the structure of the supply network (2), as well as the matching between the supply network and the product architecture (3). As literature provides numerous approaches to support (1) and (2), the paper at hand focuses on the matching between product architecture and supply network on the level of architectural attributes.
This paper provides a systematic review on approaches for the matching between the product architecture and the supply network within product development. The elaborated overview allows a distinct classification of approaches and the elaboration of future research.

Keywords: Product architecture, Collaborative design, Concurrent engineering (CE)

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1 INTRODUCTION

Manufacturing firms concentrate on their core competences to prevail in fierce competition fertilized by emerging global markets and a transformation from mass to niche markets (Nepal et al. 2012; Fixson 2005; Prahalad et al. 2000). This concentration lead manufacturing firms to shift large shares of their value creation in development and production to their suppliers (Bardi 2002). As a result, the supply network drives the economic performance of manufacturing firms through three measures reported by (Behncke, Walter, et al. 2014): (1) individual performance of the selected suppliers (Vanteddu et al. 2011), (2) their arrangement and the structure of the supply network (Min & Zhou 2002), (3) and matching between the supply network and the product architecture (Pero et al. 2010). As literature provides numerous approaches to support (1) and (2), the paper at hand focuses on the matching between product architecture and supply network (3). Approaches to support (1) and (2) can be taken from the literature reviews by (Beamon 1998) or more recent (Behncke et al. 2013).
According to (Gan & Grunow 2013) the matching between product architecture and supply network founds on decisions made upon those two dimensions in early phases of product development. Decisions are made on different levels. These levels are describe by (Gan & Grunow 2013) as architectural, detailed and dynamic attributes in the dimensions of the product architecture and the supply network. Thereby, the level of architectural attributes promises the biggest impact on the matching, so that this level is focused by the paper at hand. Within product development, decisions upon the product architecture and the supply network are commonly made in sequence. This lead to suboptimal decisions, as existing approaches provide local-optimal solutions for the different steps in the decision sequence (Nepal et al. 2012) referring to (Gunasekaran 1998). (Gan & Grunow 2013) foster a simultaneous decision making through the concurrent design of the product architecture and the supply network, which promises an ideal performance of the entire supply network. As a result, the ability to design the product architecture in parallel to the supply network evolves as a key competence of manufacturing firms (Gan & Grunow 2013).
(Gan & Grunow 2013) provide an initial overview of approaches for the matching, although they focus on trade-off between product architecture- and supply network attributes and neglect a classification that focuses on the approaches itself. This leads to the objective of the paper at hand that grasps to provide an overview of available approaches as well as a distinct classification of approaches for the matching of product architecture and supply network in early phases of product development.

1.1 Product Architecture

The product architecture (PA) represents the technical product in early phases of product development (Ulrich 1995). National and international literature draws a quiet homogenous picture of the term, while referencing on three core publications from (Otto & Wood 2001; Ulrich 1995) in English and (Göpfert 2009) in German. Table 1 summarizes these definitions. The publications define the PA consistently as: (PA.A) the arrangement of product functions (structure of functions); (PA.B) the arrangement of physical components of the product (structure of components); and (PA.C) the assignment of functions to physical components (transition dependencies). However, the definitions exhibit slight differences according to the embodiment of the arrangement of product functions (PA.A) and physical components (PA.B). (Göpfert 2009) describes a strict hierarchical structure within the arrangement of functions (PA.A) and the arrangement of physical components (PA.B), while (Ulrich 1995) defines a network structure (heterarchy). (Otto & Wood 2001) refer to a hierarchical structure of physical components through the decomposition of modules into components (PA.B), according to the definition of (Göpfert 2009). (Otto & Wood 2001) describe the arrangement of product functions (PA.A) as functional network, which mirrors a heterarchical structure of functions. As a result, literature provides to contradicting characteristics of the structure of functions (PA.A) that are hierarchy (●) and heterarchy (○). Characteristics of the assignment of functions to physical components (PA.C) is not described in detail by any of the mentioned definitions in table 1 (◎). For the arrangement of physical components (PA.B), literature provides again two perspectives; heterarchic (●) and hierarchic (○) structures. (Otto & Wood 2001; Ulrich 1995) emphasis the relevance of the interfaces between the physical components. Table 1 summarizes the definitions and confronts their different characteristics (PA.A – PA.C). The paper at hand applies the definition of (Ulrich 1995), as a hierarchical structure of functions and components cannot be implied for a new product development per se.

Table 1. Definitions and characteristics of the PA

Definitions of PA	PA.A	PA.B	PA.C
„The architecture of the product is the scheme by which the function of the product is allocated to physical components. [...] (1) the arrangement of functional elements; (2) the mapping from functional elements to physical components; (3) the specification of the interfaces among interacting physical components." According to (Ulrich 1995, p. 420)	●	●	◎
„Structure of function and components as well as transition dependencies between both structures define the product architecture and thereby, the fundamental composition of the product" According to (Göpfert 2009, p. 79)	○	○	◎
"[...] mapping from the product function to the product form. It is the division into parts and assemblies of a product and how the functional network matches or cut across these physical divisions and interfaces." According to (Otto & Wood 2001, p. 358)	●	○	◎
Legend: ● heterarchy ○ hierarchy ◎ not discussed			

1.2 Supply Network

Literature provides numerous definitions for the term supply network (SN) that is used synonymously to the wide spread term supply chain. The term SN fosters the network character of supply chains that is essential for the matching between the PA and the SN. Various authors (Ayers 2001; Chopra & Meindl 2014; Christopher 2005; Mentzer et al. 2001) describe activities in the SN as flow of material, capital and information, which has an up- and downstream orientation (Harland et al. 2001; Mentzer et al. 2001; Christopher 2005). (Beamon 1998; Ayers 2001; Christopher 2005; Ganeshan & Harrison 1995; Mentzer et al. 2001) mention the customer as part of the SN, while (Ayers 2001) focuses the fulfillment of customer requirements as ultimate objective of activities within the SN. Thereby, most of the mentioned references (Ayers 2001; Chopra & Meindl 2014; Ganeshan & Harrison 1995; Christopher 2005; Harland et al. 2001) describe a SN. According to (Harland et al. 2001) it is to be distinguished between a SN and a supplier network. Thereby, a supplier network represents a more complex structure where suppliers have multiple dependencies through a number of interacting SNs (Harland et al. 2001). Figure 1 illustrates a supplier network (grey and black) that is composed of two SNs. One distinct SN within the supplier network is represented by the black squares.

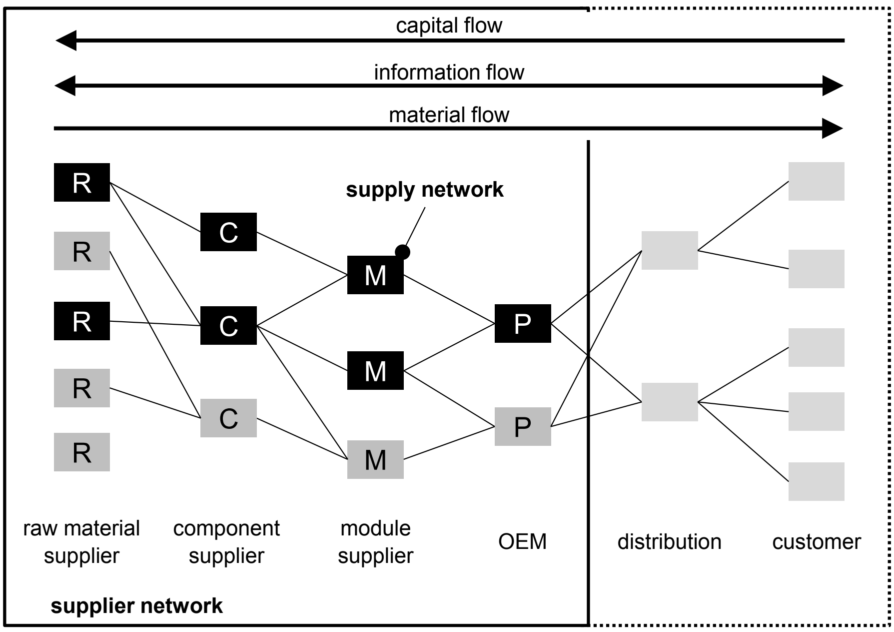

Figure 1. Distinction of the terms Supply Network and Supplier Network

2 RESEARCH METHODOLOGY

This paper presents a systematic review of literature on approaches for the matching of the PA and the SN from 2004 to 2014. The search for publications was limited to following literature databases; ScienceDirect (http://www.sciencedirect.com), SCOPUS (http://www.scopus.com), Web of Science (http://webofknowledge.com), and Google Scholar (http://scholar.google.de) as the intention of the paper at hand is to give an overview of recent approaches. The literature search uses a variation of keywords that steams from both dimensions of the matching (PA and SN). Table 2 illustrates those keywords as well as the search results. Thereby, relevant papers are identified by a content analysis according to three criteria:

- utilization of structural information for the matching,
- approach for the matching of PA and SN, or
- guideline for the matching of PA and SN.

Therewith, the number of relevant papers was reduced to twelve publications. A detailed description of the underlying approaches is provided in section 3. Several papers that are not included in the literature review deal with dependencies between product platforms and SNs. Those approaches are considered related to the topic, as product platforms might influence the PA. In order to foster a distinct investigation of the matching, these influencing factors are excluded for the paper at hand. For further information on the influence of other areas on the matching between the PA and the SN, the authors refer to (Behncke et al. 2015). Furthermore, publications that are not providing an own approach, such as literature reviews or case studies were excluded from the classification. Table 2 illustrates the combination of keywords including the division of publications into relevant out of the total number of search results. Thereby, publications might appear multiple times within the different combinations of keywords as well as within different databases.

Table 2. Definitions and characteristics of PA

Set of Keywords	Product Architecture		Product Structure		Modul(arity)		Product Design	
Supply Chain Design	74 (4)	10 (2)	63 (1)	1 (0)	409 (4)	37 (2)	333 (4)	120 (9)
	6 (1)	619 (10)	2 (0)	485 (7)	39 (6)	1510 (9)	74 (8)	2630 (10)
Supply Chain Network	41 (2)	5 (1)	72 (1)	6 (0)	508 (2)	46 (1)	350 (2)	52 (3)
	1 (0)	248 (8)	3 (0)	409 (6)	35 (2)	2010 (7)	17 (2)	2170 (7)
Supply Chain Configuration	27 (4)	7 (2)	38 (1)	2 (1)	160 (4)	19 (3)	117 (4)	30 (5)
	5 (2)	241 (10)	2 (1)	201 (6)	24 (4)	636 (8)	15 (4)	721 (11)
Network of Suppliers	20 (1)	0 (0)	16 (0)	1 (0)	108 (1)	3 (0)	93 (1)	3 (0)
	0 (0)	169 (0)	0 (0)	87 (0)	4 (0)	527 (0)	1 (0)	907 (0)
Supplier Network	37 (1)	6 (0)	22 (0)	0 (0)	199 (1)	5 (0)	173 (1)	4 (0)
	1 (0)	207 (1)	0 (0)	145 (0)	5 (0)	740 (1)	2 (0)	1050 (2)
Supply Network	57 (2)	2 (0)	81 (0)	7 (0)	980 (2)	166 (0)	374 (2)	23 (0)
	2 (0)	336 (3)	7 (0)	475 (1)	476 (0)	5470 (1)	11 (0)	2640 (3)
legend:	*Science Direct*	*Scopus*	*total number of search results (number of relevant publications)*					
	Web of Science	*Google Scholar*						

Based on this results, relevant publications were subject of a forward- and backward search that covers the investigation of the lists of reference within the papers (backward) as well as an exploration, which authors reference on the relevant publication (forward). The latter is featured by the literature databases and completes the systematic literature review of the paper at hand. However, forward- and backward search did not provide further relevant publications. Table 3 summarizes the relevant publications according to the indicated combination of keywords.

Table 3. Relevant publications

Keyword set	Product Architecture	Product Structure	Modul(arity)	Product Design
Supply Chain Design	[1]; [2]; [3]; [4]; [6]; [7]; [8]; [11]; [12]	[2]; [3]; [4]; [6]; [7]; [11]; [12]	[1]; [2]; [3]; [4]; [5]; [6]; [7]; [8]; [11]; [12]	[1]; [2]; [3]; [4] [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12]
Supply Chain Network	[1]; [2]; [3]; [4]; [5]; [6]; [7]; [11]	[2]; [3]; [4]; [6]; [7]; [11]	[1]; [2]; [3]; [4]; [5]; [6]; [7]; [11]	[1]; [2]; [3]; [4]; [5]; [6]; [7]; [9]; [11]
Supply Chain Configuration	[1]; [3]; [4]; [5]; [6]; [7]; [8]; [11]; [12]	[3]; [4]; [6]; [7]; [11]; [12]	[1]; [3]; [5]; [6]; [7]; [8]; [11]; [12]	[1]; [3]; [4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12]
Network of Suppliers	[1]	-	[1]	[1]
Supplier Network	[1]; [5]	-	[1]; [5]	[1]; [5]; [9]
Supply Network	[1]; [6]; [8]	[6]	[1]; [6]; [8]	[1]; [6]; [8]; [10]

References: [1] (Behncke et al. 2014); [2] (Chiu et al. 2009); [3] (Chiu & Okudan 2011); [4] (Okudan 2012); [5] (Chiu & Okudan 2014); [6] (ElMaraghy & Mahmoudi 2008); [7] (Famuyiwa & Monplaisr 2007); [8] (Gan & Grunow 2013); [9] (Gokhan et al. 2010); [10] (Graves & Willems 2005); [11] (Nepal et al. 2012); and [12] (Ülkü & Schmidt 2011).

3 APPROACHES FOR MATCHING BETWEEN THE PA AND THE SN

This section provides a detailed overview of relevant approaches for the matching between the PA and the SN (section 3.1) to enable the classification of approaches (section 3.2). This classification is used to derive future research directions in the field of the concurrent PA and SN design (section 3.3).

3.1 Overview of approaches

[1] (Behncke, Walter, et al. 2014) deliver a multi-stage approach to match the SN with the PA using structural information of both perspectives. The four-step procedure implies the following tasks: information acquisition for the system model (A), creation of potential PA alternatives (B.1) and creation of potential SCN alternatives (B.2), comparison of the solution space of SCN and PA alternatives (C), and lastly selection of matching alternatives (D). The simultaneous formation of alternatives of the PA and the SN during step (B) allows the simultaneous coordination (or matching) of the PA and the SN. The entire solution space for exclusive clusters is captured for both the alternatives for the PA as well as the alternatives for the SN. The quality of the matching is indicated by a conformity index CI, defined by the rate between matching relations to the total number of possible relations; a higher conformity index indicates a better matching between the PA and the SN.

[2] (Chiu et al. 2009) present a methodology for the integration of decisions regarding the SN in the phase of product design (or for the simultaneous optimization of decisions regarding the PA and the SN). The first step of the methodology consists of the creation of an Energy-Material-Signal (EMS) functional model based on the functional requirements of the product and the identified sub-functions, to present the functions of the product. A design repository is used to generate potential components for all sub-functions, providing multiple potential design concepts. In order to select the best conceptual design, the design concepts are finally screened using a Design for Assembly (DfA) index and a Design for Supply Chain (DfSC) index. The authors only consider modular PAs. As a result, they do not examine the entire solution space of possible alternatives of the PA. Hence, the solution space of possible alternatives of the SN is limited (or reduced). In addition to matching between the PA and the SN, the approach put special emphasis on the DfA.

[3-5] The method proposed by Chiu & Okudan (2011, 2012 & 2014) allows the simultaneous optimization of decisions regarding the PA and the SN design during the early stages of product

development. The refined methodology – based on the original method by (Chiu et al. 2009) – takes product functions, DfA as well as SN perspectives into account simultaneously. The methodology derives an Energy-Material-Signal (EMS) functional model based on the functional requirements of the product and the identified sub-functions. Using the data from the EMS diagram and a design repository, the methodology foresees to generate potential design concepts. These concepts are rated according to their DfA index. Unlike (Chiu et al. 2009), the methodology is not using a DfSC index. After an analysis of the components according to their suitability for a possible bundling in a module, the concepts are modularized by using the decomposition approach. This is a matrix based methodology. Two matrices result from this step: a suitability matrix and an interaction matrix, also called design structure matrix (DSM). The interaction matrix shows the interactions between the components. The suitability matrix represents the suitability for an inclusion of the components in a module. The synchronization of PA and SN is taking place by using a graph-based transition matrix, which represents the possible PA alternatives and links the functions of the PA and the SN design. The transition matrix represents all possible assembly orders of the complete product in one matrix. Combining the transition matrix and a mixed integer programming (MIP) model, the methodology allows to optimize both the PA and the SN simultaneously. Thereby, the challenge in the SN is selecting a set of suppliers that are able to produce the product. The MIP model calculates the SN performances for two scenarios; (1) minimizing the total cost of the SN and (2) minimizing the total SN lead-time.
[3] (Chiu & Okudan 2011) The major difference of this publication to [4] and [5] is the comparison of two phases. Phase 1 considers just the concept with the best DfA index for the optimization of component costs. In phase 2 takes all possible PAs and SNs issues into account. In the last step, the results of both phases are compared to identify the most competitive PA and corresponding SN. The authors compare the performance results of the SN (time and cost) for a simultaneous (phase 1) and sequential optimization (phase 2).
[4] (Okudan 2012) analyzes the impact of varying modularity level (measurable by the number of modules in a product) on the SN performance. For this purpose different modular PAs (of two or three modules) are examined and compared using an industrial case study. From their results, Chiu & Okudan (2013) conclude that a higher modularity is advantageous for a time-based performance of a SN, and that a reduced modularity yields superiority in terms of cost performance.
[5] (Chiu & Okudan 2014) compare two different SN scenarios (centralized and decentralized) as well as their performances using the bootstrap technique. The results indicate that the decentralized SN scenario is advantageous for time performance of the SN, while the centralized SN scenario promises a superior cost performance. According to Chiu & Okudan (2014), a modular PA should be coordinated with a modular SN design.

[6] (ElMaraghy & Mahmoudi 2008) present a decision support model for simultaneous determination of the optimal module structure of a product and the corresponding configuration of the SN in a three-level system consisting of suppliers, manufacturing and distribution channel. Based on the given PA alternative the model determines the modular PA and the associated SN with the lowest overall costs of the latter. The approach is formulated using integer linear programming (ILP) and the mathematical optimization tool Lingo. An optimal matching of the PA and the SN is not focused as the approach is based on predetermined PA alternatives. The approach does not consider the entire solution space of PA and SN alternatives; only modular structures are taken into account.

[7] (Famuyiwa & Monplaisr 2007) suggest a quantitative framework for determining the optimal (modular) PA, taking into account several objectives concerning PA and SN design. These objectives include domains of customer-related attributes (e.g. quality), production (manufacturability) and the SN. The multi-criteria model is formulated using the method of goal programming (GP) and is solved using a genetic algorithm (GA). The optimization method is used to determine the optimal modular PA and supplier selection, taking into account the pre-defined objectives.

[8] (Gan & Grunow 2013) deliver no approach for the matching of the PA and the SN, as they introduce a framework called concurrent Design Attribute - Trade-Off Pyramid (CDA-TOP) to structure the simultaneous product development and SN design as well as to illustrate the trade-off domains. (Gan & Grunow 2013) provide a classification scheme for the three types of attributes

(structural, detail and dynamic) and the respective interfaces between the domains of PA and SN as well as process design. In addition, CDA-TOP introduces the novel concept of design trade-off asymmetry that illustrates the impact of design attribute selection on the balance between the PA design and the SN design. Furthermore, (Gan & Grunow 2013) provide a literature review on the state-of-the-art with a focus on design trade-off attributes and methodologies used in concurrent PA and SN design.

[9] (Gokhan et al. 2010) investigate and evaluate the potentials of a design guideline called DfSC. This directive is used to solve the simultaneous optimization of decisions in product development and SN by using mathematical modeling and optimization methods. DfSC has the objective to reduce the cost of the product life cycle, to improve product quality and to increase the cost-effectiveness of all partners in the SN. (Gokhan et al. 2010) examine the effects of product design and re-design on the structure of the SN. This paper aims to quantify these effects in order to show a better understanding of trade-offs between the benefits and the costs of various alternatives of the SN.

[10] (Graves & Willems 2005) present a model for the configuration of a supplier network for new products (whose PA is set in advance) as well as for the investigation of optimal configuration strategies for this type of supplier networks. This publication presents a tool for decision support during product development. The central question is to determine suppliers, components, processes and modes of transport in the supplier network. (Graves & Willems 2005) model the supplier network as a network of stages. Each stage performs a necessary function, such as procurement, assembly or transport. One or more options exist per stage that meet the requirements of the function of the product. The problem consists of selecting the option that minimize the total cost of the supplier network. This problem is formulate as an optimization problem that is solved by the model of (Graves & Willems 2005).

[11] (Nepal et al. 2012) present a multi-objective approach to optimize the matching of the PA and the SN design. The procedure consists of three steps: (1) selection of the PA, (2) assessment of potential suppliers, and (3) optimization of the SN. The authors provide a fuzzy logic based algorithm to compute a compatibility index to determine the appropriate suppliers for the given PA. The aim of this optimization procedure is to determine the optimal SN for a selected PA under consideration of the following two objectives: minimizing the total cost of the SN and maximizing the compatibility index of the SN. The approach applies a weighted goal programming model and a GA for the optimization. It should be noted that either modular or integral PA are taken into account. The results indicate that higher numbers of modules in the SN require a higher compatibility index of the SN. Another finding is that higher numbers of nodes in the SN result in a higher flexibility ratings of the SN.

[12] (Ülkü & Schmidt 2011) do not provide an approach for matching of the PA and the SN, as they present design guidelines for the coordination of PA and SN. The paper focuses on the analysis of the link between the decisions of the PA (degree of modularity, i.e. extent in which a PA is modular or integral) and the SN configuration (i.e. decision, whether product development is done internally by the manufacturer in an integrated SN or in collaboration with a supplier in a decentralized SN). The authors discuss three development alternatives to deliver the optimal degree of modularity as a function of the size of the market, supplier capabilities and characteristics. The results indicate that a modular PA improves the performance of corporate development, but weakens the interactions between the product development teams at the same time. According to (Ülkü & Schmidt 2011) the degree of modularization should be chosen wisely, since modularization reduces the individual product performance.

3.2 Classification of approaches

Based on the overview of approaches in the previous section, table 4 presents a classification of the approaches. There are four substantial categories that vary substantially between the presented publications: approach, domain, sequence and solution space.

Approach – The majority of approaches use mathematical models to derive an ideal solution for the matching between the PA and the SN [1-7, 10 and 11], while others provide distinct suggestions for the matching in the field of PA or SN design [8, 9 and 12]. Those suggestions are summarized and prepared to serve as guidelines in early phases of product development. Furthermore, the presented approaches vary in terms of the employed quality criterion for the matching. While [2-4] focus on the optimization of a DfA and DfSC Index along with explicit performance criteria of the SN (cost and lead time). [6 and 9-11] align their optimization on the performance criterion costs, however [11] is considering a Conformity/Compatibility Index for the PA and the SN simultaneously. Approaches that derive explicit performance criteria of SNs (cost and lead time) require operational data of the SN that are not available in early phases of product development. [1] focus the optimization of the matching on a Conformity Index that is directed on a structural or architectural match between the PA and the SN. This aspect is fostered by [8] as superior level for matching the PA and the SN, especially in early phases of product development, where the information on the product and the suppliers is limited in its quality, extend and accuracy. [5 and 12] include several criteria that require operational data of the SN again.

Domain – A second category to distinguish between the approaches in table 3 are the domains that considered for the matching between the PA and SN. Thereby, four out of the twelve publications take a third domain (production) into account. Approaches [2-5] add the domain of production with the assembly processes (including a corresponding DfA guideline). Considering the production allows an integrated perspective on the optimization problem of matching the PA and SN. The authors argue that the production is subordinated compared to the matching between the PA and the SN for OEMs that shifted large shares of the value creation to their suppliers as mentioned by (Bardi 2002). All relevant approaches explicitly address the domains of PA and SN except [10] that focuses on the supplier network instead of the SN. As the supplier network is composed of the sum of potential SN alternatives, this approach considers the SN implicitly.

Sequence – Another category that characterizes the approaches for the matching of the PA and the SN is the sequence of decisions. The majority of approaches (nine) take a pre-defined PA as basis to derive SN alternatives [2-7 and 10-12], while three approaches foster a simultaneous procedure [1, 8 and 9]. Thereby, the sequence influences the solution space significantly, as those approaches are not considering further PA alternatives for the matching as well as might exclude certain SN alternatives. The third possible sequence for the matching – pre-definition of the SN – is not employed by any of the relevant approaches. This is understandable as a pre-definition implies that an OEM sources suppliers before the product is envisioned. Suppliers that are assigned for the product planning and development might be an exception as they are sourced at the very beginning of product development.

Solution space – The approaches differ in the extent of the captured solution space. This category refers to ratio between the amount of considered solutions for the matching and the possible solutions. In essence the solution space presents the different alternatives to cluster either the PA or the SN. Nine approaches [1-7 and 11] execute the matching between the PA and the SN based on a limited number of solutions. [8, 9 and 12] do not feature any information on the solution space as they provide guidelines that advice decision makers at the matching process. [10] just considers one singular solution for the matching. [1] provides a procedure that derives the entire solution space for exclusive clusters only. However, there are potential solutions for the matching between the PA and the SN that represent non-exclusive clusters. As a result, [1] is exploring a limited solution space.

Table 4. Classification of approaches

Ref.	Approach	Domain	Sequence	Solution Space
[1]	mathematical model	PA and SN	simultaneous	limited
[2]	mathematical model	PA, SN and Production	pre-defined PA	limited
[3]	mathematical model	PA, SN and Production	pre-defined PA	limited
[4]	mathematical model	PA, SN and Production	pre-defined PA	limited
[5]	mathematical model	PA, SN and Production	pre-defined PA	limited
[6]	mathematical model	PA and SN	pre-defined PA	limited
[7]	mathematical model	PA and SN	pre-defined PA	limited
[8]	guideline	PA and SN	simultaneous	-
[9]	guideline	PA and SN	simultaneous	-
[10]	mathematical model	PA and SN	pre-defined PA	singular

[11]	mathematical model	PA and SN	pre-defined PA	limited
[12]	guideline	PA and SN	pre-defined PA	-

References: [1] (Behncke, Walter, et al. 2014); [2] (Chiu et al. 2009); [3] (Chiu & Okudan 2011); [4] (Okudan 2012); [5] (Chiu & Okudan 2014); [6] (ElMaraghy & Mahmoudi 2008); [7] (Famuyiwa & Monplaisr 2007); [8] (Gan & Grunow 2013); [9] (Gokhan et al. 2010); [10] (Graves & Willems 2005); [11] (Nepal et al. 2012); and [12] (Ülkü & Schmidt 2011).

3.3 Principle directions for practitioners and future research directions

The comparison of approaches in table 4 earmarks communalities and differences that support practitioners to select an approach for their specific challenge. Thereby this paper intends to provide some principle directions for the appliance of approaches within the phases of product development.

Guidelines – as presented by [8, 9 and 12] – give an overview of standards and basic instructions for the matching between the PA and the SN. They have a strategic character and allow practitioners to set the principle boundary conditions for the matching. Therefore, guidelines retrieve their potential in very early phases of product development (e.g. product planning). Mathematical models promise ideal solutions within the defined boundary conditions through their optimization approaches. However, early phases of product development (e.g. conceptual design) do not provide operational data of the SN, which are required by most of the approaches except [1] and [11]. These approaches use structural information of the PA and the SN as they focus on a Conformity and Compatibility Index. This information is available early in product development, which allows their application within conceptual design. Succeeding phases of product development provide more operational data on both the PA and the SN, which is a precondition of the other approaches [2-7, 10 and 12]. They have a more operative character as they are used to optimize upon the pre-defined PA and SN within the set boundary conditions of the guidelines. These approaches provide a more integrated view on the optimization problem as they consider the production in addition to the domains PA and SN. As argued before, the production is subordinated compared to the PA and the SN for OEMs that shifted large shares of the value creation to their suppliers (Bardi 2002). As a result, this paper suggest to set boundary conditions already in product planning using guidelines [8, 9 and 12], while advising a preliminary optimization featuring structural information in the phase of conceptual design as a preselection of matching the PA and the SNs [1 and 11]. Those solutions are basis for the final mathematical optimization with operational data of both the PA and the SN after the conceptual design, which is featured by [2-7, 10 and 12].

This paragraph derives future research directions based on the principle directions for practitioners. The majority of approaches do not investigate the entire solution space, although those models would provide an adequate foundation. These approaches miss comparable good solutions for the matching. This is intensified through the chosen sequence starting with a pre-defined PA, as there might be PA alternatives in the solution space available that better match the SN. The central aspect for the definition of the PA is the composition of modules. Clustering techniques are deployed to define these PA alternatives, however (Behncke, Maurer, et al. 2014) report that those techniques miss ideal solutions. In order to allow a simultaneous decision sequence upon PA- and SN alternatives – fostered by (Gan & Grunow 2013) – an excessive search of the entire solution space promises to find any ideal solution. This challenges established cluster techniques as well as the matching between the PA and the SN, as a high number of alternatives for the PA as well as for the SN need to be considered.

4 SUMMARY AND OUTLOOK

This paper provides a systematic review of publications on the matching between the PA and SN. Based on an overview of approaches, this paper derives a classification that earmarks the commonalties and differences in terms of the approach, considered domains, the sequence of decisions and the captured solution space. These categories are used to derive principle directions for the application of approaches within the different phases of product development as well as emphasis the future research directions that fosters a search of the entire solution space combined with a simultaneous decision sequence to ensure global-optimal solutions for the matching between the PA and the SN.

A first step of future work is the preparation of related publications that have not matched the primary objective of the paper at hand, but affect the matching such as guidelines that aiming for the design of product families. Another step is to elaborate an approach that matches the future research directions and support practitioners to achieve a matching between the PA and the SN in product development. The directions for the latter are already predetermined through the implications on the presented approaches and their application within the different phases of product development.

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