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Context Specific Complexity Management – A recommendation model for optimal corporate complexity

Peter Schott
Lange Gasse 20, 90403 Nuremberg, Germany
Phone: +49 911 5302 450
Email: peter.schott@fau.de

Felix Horstmann
Lange Gasse 20, 90403 Nuremberg, Germany
Phone: +49 911 5302 450
Email: felix.horstmann@fau.de

Freimut Bodendorf
Lange Gasse 20, 90403 Nuremberg, Germany
Phone: +49 911 5302 450
Email: freimut.bodendorf@fau.de

Abstract

Companies face emerging external complexities that they must respond to with internal complexity to be able to perform on a superior performance level. On that account, an application-oriented methodology to support the context specific selection of appropriate complexity management methods for accomplishing the optimal level of internal complexity is lacking. A complexity management model is introduced that tackles this deficiency. Based on the identification of 37 complexity drivers that determine corporate complexity and 81 complexity management methods from literature, an assignment matrix with 2,997 relations between complexity drivers and methods is stretched. A scoring algorithm uses these relations to generate a sorted list of appropriate management methods for a specific complexity context determined by relevant complexity drivers. The approach is operationalized by a software prototype and evaluated through six interviews with experts from the field who confirmed practical relevance, appropriateness, and value-added of the provided management recommendation.

Keywords: complexity management, recommendation model, complexity drivers, law of requisite variety, scoring algorithm

1 INTRODUCTION

Modern industrial companies face an environment characterized by uncertainty and dynamics (Vrabic 2012). Thus, the basis of a company's long-term success lies in the adaptability of its business processes. In industrial practice, however, this desire for flexibility often leads to an increased company internal complexity (Vrabic 2012). Pellissier (2012) states that both research and practice come to the conclusion that overly complex companies cannot survive in the market over the long term. This basic statement is supported by numerous other studies (e.g., Kim and Wilemon 2012; Axley and McMahon 2006). On the other hand, Axley and McMahon (2006) see a certain degree of complexity as a positive and essential property of companies. They explain that a system can achieve more flexibility with an increasing complexity of elements and relations, which in turn increases the company's ability to adapt to different environmental conditions. This leads to an extended survivability of the company (Pellissier 2012; Isik 2010).

Owing to the fact that in industrial companies production greatly contributes to the value added, it can be assumed that the complexity of production processes significantly influences the overall corporate complexity (Kim and Wilemon 2012). Hence, it is necessary to tailor the application of complexity management methods to the production specific initial situation. A thorough outline of existing complexity management methods is lacking. As a consequence, complexity management poses a considerable challenge for companies (Pellisier 2012; Axley and McMahon 2006). Responsible managers (e.g., production managers) oftentimes lack comprehensive knowledge about the entirety of available complexity management methods or solely rely on a specific method they already applied in other application scenarios (Hickey and Davis 2004).

Therefore, this contribution addresses this gap and presents an approach that provides the possibility to systematically integrate specific situational production contexts into the selection of appropriate management methods. Like this, the approach expands the existing work in complexity research by a systematic linkage of the area of application with the corresponding managerial solution space.

Consequently, the aim of this work is to design and develop an approach for the recommendation of complexity management methods in form of a rated list of context-appropriate complexity management methods. This results in the following research questions:

RQ1: Which complexity drivers exist in production-related fields of application?
RQ2: Which methods exist to effectively manage complexity?
RQ3: How can appropriate methods for a specific complexity issue be identified and recommended?

To answer these questions, first complexity drivers are identified and classified based on existing literature. Subsequently, appropriate and well-tried complexity management methods are collected from literature. Based on this groundwork, a scoring algorithm to provide users with context-appropriate management methods is deduced. This bases on a quantified allocation of complexity drivers and appropriate methods by means of a two-dimensional assignment matrix.

Finally, the evaluation of the presented recommendation approach by means of six semi-structured expert interviews is briefly displayed. The contribution concludes with a discussion of impact and limitations and a summarizing conclusion.

2 BACKGROUND

Companies are generally understood as complex systems (e.g., Holland 2006; Pellissier 2012; Suh 2005). A company's complexity has numerous different drivers that can influence and reinforce each other. Literature oftentimes differentiates between structural and functional complexity (Godfrey-Smith 1998). The structural complexity is to be understood as an objective characteristic of a company. It includes exogenous complexity (social complexity, market complexity) and endogenous complexity (correlated and autonomous corporate complexity). The handling and management of complexity, however, always associates with the subjective perception of internal and external business factors and subsumes functional complexity. Pellissier (2012) considers a certain level of business complexity as a positive and vital capacity. A company therefore does not necessarily reach its complexity optimum when it has the lowest possible complexity (Marti 2007, Kim and Wilemon 2012). Ashby's Law of Requisite Variety supports this hypothesis (Ashby 1970). He states that only an equally strong internal system complexity can counter the complexity of the system environment (e.g., the company environment) (Ashby 1970). Thus, it is clear that both a deficiency as well as an excess of complexity impede the sustainable business success alike. Consequently, complexity can never be completely eliminated without jeopardizing the company's existence.

A sizable number of researchers delve quantitative dimensions of complexity and especially focus on the measurement of complexity (e.g., Smart et al. 2013, Isik 2010, ElMaraghy and Urbanic 2003, Vrabic 2012). In this context, for example Smart et al. (2013) apply an information-theoretic view on dynamic and static complexity measures and concentrate on the amount of information needs within manufacturing systems. Isik

(2010) stresses an entropy-based approach for measuring supply chain complexity and ElMaraghy and Urbanic (2003) emphasize on complexity measurement considering process, product and the cognitive manufacturing system complexity. Vrabic (2012) assesses a metric for operational complexity to support the subsequent derivation of management activities. They clearly dissociate the scope of their research from the management of complexity that chronological succeeds the measurement of complexity (Isik 2010).

Nevertheless, several complexity management approaches that substantially build on the (quantitatively or qualitatively) determined condition of system states are described in literature (e.g., Marti 2007; Windt et al. 2008; Urbanic and ElMaraghy 2006). Marti (2007) investigates the trade-off between internal and external product complexity dimensions and derives guidance for optimizing product architecture. Areas up- and downstream (or parallel) to the product design are not considered. Windt et al. (2008) operationalize complexity in the dimensions systematic, organizational and time-related complexity by creating complexity vectors. Analyzing these vectors allows figuring out the optimal configuration of the manufacturing system. Anyway, Windt et al. (2008) also rather focus on the complexity-based determination of manufacturing systems than on the management of complexity within a settled system. Urbanic and ElMaraghy (2006) scrutinize manufacturing complexity to develop a manufacturing complexity index with focus on the identification of product and production related leverage points for optimizing complexity, but do not provide methodical guidance for coping with this complexity. Suh (2005) bases his complexity research on the time independent and time dependent characterization of manufacturing systems and derives implications how to optimize the system layout with regard to the fulfillment of production tasks. Methodical guidance for coping with complexity within an (temporary) immutable manufacturing system is no focal point of his approach. Other approaches such as Gegov et al. (2014) or Bosch et al. (2013) provide very abstract methodologies that are hard to operationalize in practice. The following table summarizes the described research approaches.

Table 1: Literature overview

Author(s)	**Basic idea/concept**	**Complexity measurement**	**Complexity management**	**Management focus**	**Application orientation**
Kirchhof (2003)	Holistic complexity management approach		X	Transparency of system complexity	Low to middle
Suh (2005)	Optimizing system design based on complexity assessment		X	System re-design	Middle to high
Urbanic and ElMaraghy (2006)	Complexity-based process modeling in production management		X	Process modeling	middle
Marti (2007)	Optimizing product architecture based on product complexity		X	Product architecture	middle to high
Windt et al. (2008)	Characterization of complexity in production systems	X		None	middle
Lindemann (2009)	Optimizing product design based on complexity assessment		X	Product design	middle
Isik (2010)	Optimizing complexity in supply chains	X		None	low to middle
Vrabic (2012)	Assessing manufacturing system complexity based on statistical complexity metric	X		None	middle
Kim and Wilemon (2012)	Characterization of complexity in product development projects	X		None	low to middle
Smart et al. (2013)	Measuring system complexity based on information entropy	X		None	middle

In a nutshell, prevailing approaches either focus on the quantitative assessment of complex situations within production near fields without providing recommendations for coping with these situations or - if they do - lack practical applicability. An application oriented approach to support management of complexity by systematically mapping the problem area to the existing managerial solution space is missing. Therefore, the subsequently described approach is designed to provide a quantitatively rated recommendation of management methods that most likely suit to defer the corporate complexity towards the complexity optimum.

3 COMPLEXITY MANAGEMENT RECOMMENDATION APPROACH

3.1 Methodology

One of the primary goals of this work is the identification of complexity drivers and suitable methods for complexity management in production processes. The identification bases on the approach of Webster and Watson (2002) and comprises three basic steps. First, leading journals and publications are considered. Second, a backward path review by analyzing citations from the publications identified in step one is conducted. Third, the insights from the first two steps form the input for a forward path review. In accordance with the approach of Parthiban et al. (2013), some selection criteria based on analogous research approaches were chosen to select and define appropriate complexity drivers and management methods. These criteria are (1) a comparable level of granularity, (2) the assignability to production or production-related fields of application, and (3) the availability of more than one distinct source. In order to make the identified complexity drivers and management methods usable for the complexity management recommendation, they are subsequently grouped into classes referring to Belliveau et al. (2002).

3.2 Identification of complexity drivers and management methods

Table *2* shows the list of d=37 identified production-related complexity drivers.

Table 2: List of identified complexity drivers

d	Complexity driver	Source(s)	d	Complexity driver	Source(s)
1	Number & strength of competitors	A, B, C	20	Availability of innovative technologies	B, C, D
2	Velocity of market change & competitive dynamics	B, C	21	Length of technology life cycle	B, C, D
3	Globalization	B, C	22	Product structure, number of parts and assembly groups	B, C
4	Number & heterogeneity of customers	B, C	23	Number of products and variants	A, B, C
5	Degree of participation	A, B, C	24	Dynamics of program changes	B, C, G
6	Variety of customer requirements	A, B, C	25	Vertical range of manufacturing	B, C
7	Market dynamics	B, C	26	Number and design of interfaces	A, B, C
8	Global requirements	B, Q	27	Cross-linkage level	B, C
9	Demand uncertainty and volatility	A, P	28	Degree of standardization	B, C
10	Variety of supplier base	C, P	29	Flow of goods, financial assets and information	A, C, G
11	Diversity of sourcing strategy and concept	B, K, N	30	Degree of automation	R, S
12	Variety of sourcing objects	C, K, O	31	Number of organizational entities and hierarchy levels	A, B, C
13	Availability of resources	F, J	32	Degree of centralization	B, C
14	Demand volatility	B, C	33	Number of warehouses, employees and machines	B, C
15	Uncertainty of delivery dates and quality	B, C	34	Variety of information and communication systems and their interfaces	A, B, C
16	Number of employees and functions and their interfaces	A, E	35	Frequency and level of detail of need for management and control	B, L, M
17	Quality of Know-how, experience and qualification	D, I	36	Production logistics and material flow relations	G, H
18	Language, culture and communication barriers	A, E	37	Corporate objectives	B, C
19	Speed of technological change	A, B, C, D			
Legend of sources		Blecker and Abdelkafi (2006) – **H** Gotsch et al. (2014) – **I** Mc Kinnie (2007) – **J** Novak and Eppinger (2001) – **K** Windt et al. (2008) – **L** Pellissier (2012) – **M**		Thewihsen (2007) – **N** Salvador et al. (2002) – **O** Hsiao (2009) – **P** Wysocki (2014) – **Q** Fast-Bergelund et al. (2013) – **R** Onken and Schulte (2010) - **S**	

Following the approach of Belliveau et al. (2002), in total nine complexity driver classes could be differentiated.

Table 3 lists these classes and depicts the assignment results of the complexity drivers to the appropriate class.

Table 3: Classified complexity drivers

Class (c)	Complexity drivers (d)
C1: Competition complexity	1; 2; 3
C2: Customer and demand complexity	4; 5; 6; 7; 8; 9
C3: Supplier and sourcing complexity	10; 11; 12; 13; 14; 15
C4: Personnel complexity	16; 17; 18
C5: Technology complexity	19; 20; 21
C6: Product, product program and production program complexity	22; 23; 24; 25
C7: Process complexity	26; 27; 28; 29; 30
C8: Organizational complexity	31; 32; 33
C9: Complexity of information, planning, management and control	34; 35; 36; 37

After the identification and classification of different complexity drivers, subsequently appropriate complexity management methods that are suitable to cope with complexity are identified from literature. In this context, complexity management methods are interpreted as a generic term for all those actions, initiatives, projects or programs that can be used to systematically and reproducible influence complexity towards the complexity optimum.

To enable the assignment of different complexity drivers to adequate complexity management methods, the identified methods divide into classes following the line of action described in section 3.1. Thus, the driver classes equally serve as classification scheme for the complexity management methods and facilitate the distinction of relevant from irrelevant methods. In contrast to the classification of complexity drivers, an assignment of individual methods to more than one class is possible. In the course of the described approach, the following 81 complexity management methods could be identified and assigned to their corresponding class(es), as depicted in *Table 4*.

Table 4: Classified complexity management methods

Class (c)	Complexity management methods (m)
C1: Competition complexity	Creation of imitation and market entry barriers; Decision about market exhaustion or dismissal; Market diversification; Exploitation of market niches
C2: Customer and demand complexity	Decision about market exhaustion or dismissal; Exploitation of market niches; Market diversification; Market segmentation; Direct and indirect customer settlement; Quality Function Deployment; Blocking; Packaging; Premium standards; Premium finishs; Direct and indirect program settlement; Variety Reduction Program; Creation of product-market combinations; Creation of performance systems; Build-to-order
C3: Supplier and sourcing complexity	Supplier integration; Creation of company networks; Creation of company networks; Full-range assortment through acquisition; Modular and system sourcing; Single sourcing; Variant Mode and Effect Analysis; Just in Time; Just in Sequence; Vendor Managed Inventory; Kaizen
C4: Personnel complexity	Creation of company networks; Personnel development and qualification; Competency development programs; Shopfloor management; Outsourcing
C5: Technology complexity	Integration or elimination of technologies; Creation of technology combinations and technology platforms; Simultaneous engineering; Creation of company networks; Outsourcing
C6: Product, product program and production program complexity	Quality Function Deployment; Failure Mode and Effects Analysis; Blocking; Packaging; Reverse Engineering; Integral and differential design; Multimix manufacturing; Third party sourcing; Design for variety; Premium standards; Premium finishs; Direct and indirect program settlement; Variety Reduction Program; Functions integration; Standardization; Modularization; Systematization; Platforms; Sequence planning; Variant Mode and Effect Analysis; Outsourcing; Modular and system sourcing; Single sourcing; Simultaneous Engineering; Reduction of vertical range of manufacturing; Substitution of horizontal manufacturing through horizontal assembly; Variant dislocation; Dislocation of decoupling point, Lean Production
C7: Process complexity	Mizusumashi; Sequence planning; Multimix manufacturing; Dislocation of decoupling point; Process segmentation; Horizontal process integration; Outsourcing; Workflow analysis; Planning of the standard organization model; Value analysis; Kaizen; Variant Mode and Effect Analysis; Self-organization; Single Minute Exchange of Die; Andon; Autonomation; CONWIP; Heijunka; Poka Yoke; Shopfloor management; Low Cost Intelligent Automation; One Piece Flow; U-shaped cells; Line-back principle; Modularization of material flow system; Direct supply into production; Milkrun; Warehousing; Low level process analysis, Lean Production; Kaizen
C8: Organizational complexity	Kanban/Pull principle; Vertical autonomy; Hierarchy flattening; Planning of the standard organization model; Vendor managed Inventory; Drum-Buffer-Rope; Load oriented order release; Progress figure concept
C9: Complexity of	Lean Production; Build-to-Order; Six Sigma; Kaizen; Kanban; Self organization; Planning of the

information, planning, management and control	standard organization model; Single Minute Exchange of Die; Andon; Autonomation; CONWIP; Progress figure concept; Heijunka; Poka Yoke; Shopfloor management; Low Cost Intelligent Automation, Reduction of vertical range of manufacturing; Modularization of material flow system

3.3 Assignment matrix

In the previous section, complexity drivers as well as complexity management methods to cope with those drivers are identified and classified. At this point, the assignment process of methods to complexity drivers to stretch a two-dimensional assignment matrix is described. This allows the identification of suitable methods for a specific production-related complexity problem. The matrix comprises a total of 2,997 relations of m = 81 methods multiplied by d = 37 complexity drivers.

The mapping process is realized by means of a four-point scale in line with Hartley and Betts (2010). The scale aims to describe the effectiveness of the methods for specific complexity drivers. For each possible pair of complexity driver d_i and method m_x, one of the values “-“, "0", "+" or "++" is assigned. Here, "-" stands for a negative influence on the complexity. "0" means no or very little effect on the complexity. "+" denotes a positive influence on the complexity and "++" represents an extremely positive effect on the complexity level.

Method descriptions of respective literature primarily serve as the basis of the individual relations between methods and drivers in the allocation process. In about 20% of cases (for 16 methods) where the allocation of a method to one or more appropriate complexity drivers could not be directly derived from literature, a two-stage Delphi study has been conducted. For this, three experts from both a globally active producer of electronic devices as well as from a medium-sized company specialized on batch production served as participants of the study. The experts featured an average of 5.5 years of work experience in production related task fields and work as middle managers between top management and operational level in their company. All three of them explicitly had faced complexity issues in their work environment and thus featured sufficiently comprehensive expertise and experience to suit as experts (Glaeser and Laudel 2006). In the first round of the Delphi study, the experts assigned the respective methods to appropriate drivers. In the second round of the study, the experts had access to the other expert’s assessments that were anonymously made available to them. Based on this, the experts refined their rating from the first round. By doing so, the assignment results in an as objective as possible allocation. Table 5 shows an excerpt of the resulting assignment matrix. Above and to the right of the assignment matrix, aggregations of the individual ratings of relations ("-", "0", "+" or "++") can be found. The aggregation to the right of the matrix counts how many methods were rated with the values “-“, "0", "+" and "++" for a single complexity driver. It answers the following question, regarding the methodical coverage of the complexity drivers:

(1) How well are the distinct complexity drivers methodically covered by existing complexity management methods?

The aggregation above the matrix shows how many complexity drivers for a particular method exhibit an evaluation according to the defined scale. It answers the following question, regarding the methodical width and universality of the complexity management methods:

(2) How many complexity drivers does a particular method address?

Referring to Macoun and Prabhu (1999), the aggregated values (“-“, “+” and “++”) are colored to point out the beneficence of both the methodical coverage of complexity drivers by existing management methods as well as the suitability of a distinct method for different complexity drivers. Here, black values indicate high quality (i.e. high methodical coverage or width), whereas dark grey values represent medium quality and light grey values indicate a poor quality. A high number of "++" - or "+"-ratings, as well as a small number of "-"-ratings thereby result in a black coloring. On the other hand, a variety of "-"-ratings and a small number of "++" - or "+"-ratings result in light grey coloring. Whether the aggregation of individual values is considered as "high (=black)" or "low (=light grey)" does not rely on absolute figures. It depends on how the number of current valuations of the individual complexity driver or of the individual complexity management method compares to the number of the respective evaluation of all other methods and complexity drivers (Macoun and Prabhu 1999). “0”-ratings mark the non-existence of a relevant relation between a complexity driver and a complexity management method. Therefore, these aggregations will not be part of further considerations within this work.

Table 5: Assignment matrix

Complexity drivers (d) and driver classes (c)		m1	m2	m3	m4	m5	m6	m7	m8	m9	…	m80	m81	- ∑	0 ∑	+ ∑	++ ∑
∑	++	3	3	7	9	2	1	6	1	5	…	4	0				
∑	+	3	10	4	3	6	5	2	5	7	…	1	5				
∑	0	31	24	26	25	29	30	29	31	24	…	32	32				
∑	-	0	0	0	0	0	1	0	0	1	…	0	0				
c9	d37	+	+	+	+	+	+	0	0	0	…	0	0	0	52	26	3
	d36	0	+	0	0	0	0	0	0	++	…	++	+	2	37	22	20
	d35	0	0	0	0	0	0	0	0	-	…	0	0	9	34	25	13
	d34	0	0	0	0	0	0	0	0	0	…	0	0	0	54	18	9
c8	d33	0	0	0	0	0	0	0	0	0	…	++	0	0	48	17	16
	d32	0	0	0	0	0	0	0	0	0	…	+	0	2	74	4	1
	d31	0	0	0	0	0	0	0	0	0	…	0	0	0	70	8	3
c7	d30	0	0	0	0	0	0	0	0	0	…	0	0	0	69	7	5
	d29	0	0	0	0	0	0	0	0	0	…	++	+	3	44	22	12
	d28	0	0	0	0	0	0	0	0	0	…	0	+	4	41	21	15
	d27	0	0	0	0	0	0	0	+	0	…	0	+	1	51	14	15
	d26	0	0	0	0	0	0	0	+	+	…	0	+	4	42	17	18
c6	d25	0	0	0	0	0	0	0	0	+	…	0	0	0	65	8	8
	d24	0	0	0	0	0	0	+	+	+	…	0	0	1	56	8	16
	d23	0	0	0	0	0	0	++	0	0	…	0	0	1	49	8	23
	d22	0	0	+	0	0	0	++	++	0	…	0	0	0	48	16	17
c5	d21	0	0	0	++	0	0	0	+	0	…	0	0	0	63	14	4
	d20	+	+	+	+	0	0	0	0	0	…	0	0	0	64	12	5
	d19	0	0	0	++	0	0	0	+	0	…	0	0	0	66	12	3
c4	d18	0	0	0	0	0	0	0	0	0	…	0	0	0	75	3	3
	d17	0	0	0	0	0	0	0	0	0	…	0	0	3	61	12	5
	d16	0	0	0	0	0	0	0	0	+	…	0	0	0	65	14	2
c3	d15	0	0	0	0	0	0	0	0	+	…	0	0	8	69	3	1
	d14	0	0	0	0	0	0	0	0	++	…	++	0	1	65	10	5
	d13	0	+	+	0	0	0	0	0	++	…	0	0	2	72	6	1
	d12	0	0	0	0	0	0	0	0	+	…	0	0	1	68	8	4
	d11	0	0	0	0	0	0	0	0	++	…	0	0	0	72	6	3
	d10	0	0	0	0	0	0	0	0	++	…	0	0	2	70	5	4
c2	d9	0	+	0	0	0	+	0	0	+	…	0	0	0	68	9	4
	d8	0	+	+	+	++	0	0	0	0	…	0	0	0	70	8	3
	d7	0	++	++	++	+	+	++	0	0	…	0	0	0	58	18	5
	d6	0	+	++	++	+	+	++	0	0	…	0	0	1	52	14	14
	d5	0	+	++	++	+	+	++	0	0	…	0	0	0	67	11	3
	d4	0	+	++	++	++	++	++	0	0	…	0	0	1	57	13	10
c1	d3	++	+	++	++	+	0	0	0	0	…	0	0	0	70	8	3
	d2	++	++	++	++	+	0	0	0	0	…	0	0	0	64	12	5
	d1	++	++	++	++	0	-	0	0	0	…	0	0	1	72	4	4
		Complexity management methods m															

3.4 Scoring algorithm

Based on the mapping results of the previous sections, now the recommendation algorithm is described. The approach bases on the score S_{m_x} which quantitatively expresses the suitability of complexity management methods for specific complexity situations (caused by specific complexity drivers). The score allows a ranked depiction of those methods that are most likely to defer the endogenous complexity towards the complexity optimum. In order to allow a nuanced proposal sequence, the scoring algorithm bases on two independent criteria. First, it considers the number of "++" - or "+"-ratings of the respective methods, as for each complexity driver d_i there are several methods m_x with “++”- and/or “+”-rating available (see *Table 5*). Second, the scoring algorithm additionally considers the "methodical width" of the methods. This width describes the scope of applicability of a method and is quantified in the following with a numerical value according to Golden-Biddle and Locke (2007). This value increases with the number of "++" - and "+"-ratings of a specific method and decreases with a rising number of "-"-ratings.

The ratings in the assignment matrix serve as basis for calculating the width of a method and are translated into the key figure B_{d_i,m_x}. This value describes the assessment of the complexity driver d_i regarding the method m_x. It ranges from "-1" to "2" ($B_{d_i,m_x} \in [-1..2]$) and can be interpreted in accordance with Hartley and Betts (2010) as follows (see *Table* 6):

Table 6: Interpretation of B_{d_i,m_x}

Value of B_{d_i,m_x}	Equivalent value from assignment matrix
-1	-
0	0
1	+
2	++

The assignment evaluation B_{d_i,m_x} allows the calculation of the total score S_{m_x} (methodical width of the method m_x) taking the varying weightings of the ratings "++", "+", "0" and "-" into account. For this reason, "0"-ratings are entirely excluded, while "-"-ratings contribute negatively and "+" - or "++"-ratings contribute positively (single for "+" and double for "++"). This procedure ensures that the score weights those methods the most that show a high relevance to cope with a specific complexity problem (Golden-Biddle and Locke 2007).

To calculate the score S_{m_x} of the respective method m_x, the sum of all 37 ratings B_{d_i,m_x} for this method m_x is added up. By calculating all possible scores S_{m_x}, the results can be represented as a sorted list of all the scores of 81 methods m_x (sorted tuple K_m of S_{m_x}). The higher the score S_{m_x}, the higher the width of each method m_x for this respective score. This results in the mathematical relationships depicted in

Table 7.

Table 7: Calculation of S_{m_x}

Step 1	**Rating B_{d_i,m_x} (evaluation of complexity driver d_i regarding method m_x)**	$B_{d_i,m_x} \in [-1..2]$
Step 2	**Score S_{m_x} (methodical width of method m_x)**	$S_{m_x} = \sum_{i=1}^{37} B_{d_i,m_x}$
Step 3	**Sorted tuple K_m of S_{m_x}**	$K_m = \langle S_{m_1}, S_{m_2}, .., S_{m_{81}} \rangle$ with $S_{m_x} \geq S_{m_{x+1}}$

4 EVALUATION

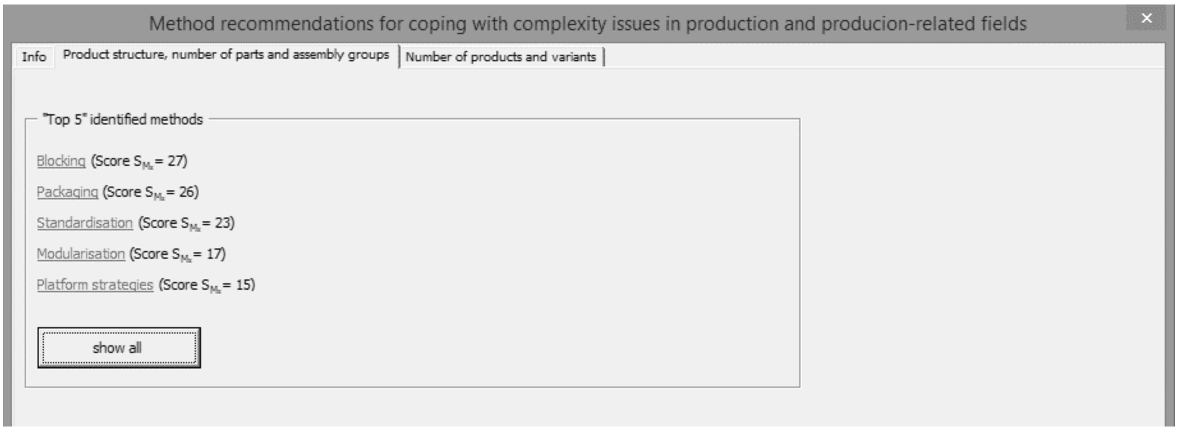
The following section shows the results of an evaluation study conducted to investigate the appropriateness, practical applicability and relevance as well as to identify potential weak-points and methodological gaps of the developed approach.

4.1 Methodology

To evaluate the approach six guided expert interviews with experts from four different large scale manufacturing companies with global business activities and a diversified product portfolio were conducted (for confidentiality reasons, the names of companies will not be mentioned). The experts have an average of 5 years of work experience in production or production-related fields. They are located in the middle management (reporting duties towards top management and instructional duties towards operational subordinates) and differ from those experts that participated in the Delphi study to stretch the assignment matrix. Following the suggestions of Glaeser and Laudel (2006), the experts that evaluated the overall approach featured explicit experience in complexity management issues in their professional environment and thus suit as experts for the evaluation study.

In advance, a software prototype that operationalizes the algorithm and visualizes the recommendation result in a user-friendly and time-saving manner was developed. The software architecture comprises the layers data management, business logic and representation, derived from functional criteria according to Jablonski (2004). The data layer contains the identified complexity drivers, the complexity management methods and the contents of the assignment matrix. The logic layer operationalizes the described scoring algorithm and the representation layer facilitates the dialogue between users and software. With the prototype, potential users are able to reconstruct the consecutive steps of the presented approach in practice to deduce the sorted tuple K_m that displays the most suitable management methods for a specific complexity issue. In the first step, the user defines the relevant complexity driver classes (c) for the current application case and details his/her entries by selecting the relevant complexity drivers that are displayed according to the ticked classes. The scoring algorithm calculates the score of all complexity management methods and identifies the ones with the highest score (see *Figure 1*). The depiction of more methods with lower scores is possible ("show all").

Figure 1: Screenshot of the complexity management method recommendation view



Furthermore, the prototype provides the user with further information about the recommended complexity management methods and proposes methods that closely relate to the originally proposed ones. By doing so, the prototype supports a high degree of flexibility and alternative options with regards to the application of different methods.

4.2 Evaluation results

The interviewees were asked to apply three scenarios from their everyday work and within their area of authority to the proposed artifact. Based on these scenarios, the experts evaluated the outcomes provided by the recommendation approach and compared them to their expectations they had without the comprehensive support. Referring to Flick (2014) an interview guideline comprising open and closed statements was applied during the interviews and the experts assessed these statements applying the following scale (derived from Lantz 2013):

Table 8: Evaluation Scale

Identifier	Value	Description
1	Total approval	Total approval with the stated statement
2	Predominant approval	Approval with the statement in essence
3	Minor deviations	Approval with the statement in essence with minor deviations
4	Significant deviations	Partly approval with the statement with significant deviations
5	Denial	No approval with the statement and denial of (almost) all essentials
0	No assessment	No assessment

The following table briefly summarizes the evaluation results and provides an overview about the appraisement of both the approach and the prototype as given by the experts.

Table 9: Evaluation overview

	Statements	**Assessment** Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
1	Complexity is highly relevant in day to day work and is an ubiquitous phenomenon that causes problems and additional workload.	1	2	1	1	1	2
2	A comprehensive support for managing complexity in day to day work is reasonable. The application of a respective software support is in general desirable.	2	2	2	3	1	3
3	The complexity management recommendation approach is intelligible. The contents of the approach are comprehensive and cope with the requirements in the field.	1	1	1	2	1	2
4	The complexity management methods integrated into the artefact provide a sufficiently comprehensive possibility of selection and constitute an outright methodical coverage.	1	1	2	2	1	1
5	The approach entails all relevant complexity drivers and complexity management methods and addresses practical needs.	1	2	1	2	1	2
6	The complexity management method recommendations provided by the scoring algorithm are feasible and suit for the handling of practical complexity issues.	2	2	2	3	2	3
7	The proposed ranking of appropriate methods corresponds with the requirements defined during the selection of relevant complexity drivers.	2	2	3	2	2	3
8	The usability of the appropriate software prototype is adequate. The representation of method recommendations as well as the short descriptions of suitable methods (including chances and risks) are useful and satisfactory.	1	1	1	2	1	2

The expert survey shows that the relevance of complexity in production near fields is recognized. Thus, the provision of support for managing complexity in general was rated as desirable and meaningful. In this context, the presented complexity management recommendation approach satisfied the experts' needs and expectations and meets their practical requirements. The integrated management methods exceed the knowledge base of the experts by far and are evaluated as valuable information base.

All experts agreed that the recommendation approach enhances their methodical knowledge significantly. Furthermore, all experts were united about the fact that the depiction of complexity drivers augments their view on complexity within their field of authority and leads to a more holistic determination of the initial situation. However, the experts 4 and 6 questioned the reasonableness of a supportive complexity management recommendation approach by itself and would rather rely on their personal expertise shaped by their long term work experience. Nevertheless, all experts considered the presented approach and the corresponding software prototype as a valuable source of inspiration and as a starting point for management activities in practice. Especially the provision of further information of potentially appropriate management methods entailing chances and risks as well as further readings and related method referrals meet the experts' expectations (especially stated by experts 1, 2, 3 and 5).

In addition to the general consent of the interviewees about the presented recommendation approach and the prototype, also some suggestions to improve the approach and the prototype could be collected. All experts agreed that the approach as well as the prototypal realization should provide the possibility to complement the database with further methods or practices from the field to customize the recommendation results. Expert 1, 2 and 4 also stated that the prototype should display the systematic steps for building the ranked method recommendation to ease the justification of the user's method choice towards superior and subordinate hierarchy levels.

5 DISCUSSION

Certain limitations with regards to dependability, reproducibility, and generalizability of the presented approach need to be mentioned. The identification of relevant complexity drivers and of complexity management methods as well as the compilation of the assignment matrix strongly rely on the qualitative assessment of research literature and expert opinions and thus run the risk of distorted results (Venkatesh et al. 2013). In addition, solely field-tested approaches without comprehensive scientific grounding are not considered for the recommendation approach. Furthermore, the scoring algorithm that calculates the rank order of the most suitable complexity management methods simplifies the interrelations between various complexity drivers and complexity management methods. The corresponding risk of an oversimplified representation of results should be investigated in further research activities. Finally, the evaluation grounds on the assessment of six experts that distinguish themselves as practitioners and middle managers in production or production near fields with sufficiently relevant work experience. Although this evaluation already provides valuable information about the presented approach, an in-depth evaluation with a greater number of participants in a field study with a pre-post-measurement of corporate complexity (compared to the complexity optimum) will be conducted.

6 CONCLUSION

The developed recommendation approach is based on a data set comprising 37 complexity drivers and 81 complexity management methods, resulting in a data pool of a in total 2,997 relations between complexity drivers and management methods. A scoring algorithm calculates the rank order of the most suitable complexity management methods for specific complexity issues. With this algorithm a selection and allocation of appropriate management methods for a distinct complex situation is provided. A corresponding software prototype operationalizes the theoretic approach and is adapted to the requirements of practitioners in production or related application fields.

The general appropriateness of the presented approach has been confirmed during six semi-structured expert interviews. To conduct the interviews, the approach was implemented in practice by using the software prototype. The prototype represents both the content-related groundwork (complexity drivers and methods) and the scoring algorithm and was applied in the course of the experts' interrogations, during which the experts assessed the completeness, applicability, and appropriateness of the recommendation approach. It was shown that the recommendation approach generally meets requirements from practitioners. It was evaluated as a valuable artifact to broaden the methodological knowledge base of managers in charge.

In conclusion, the recommendation approach for complexity management is a valuable artifact that has the potential to facilitate and support both theorists and practitioners in coping with complexity issues. Especially the line-up of the comprehensive method collection represents a worthwhile supplement to complexity management know-how. The approach helps to tailor existing management options to specific corporate situations by systematically aligning the managerial solution space with specific problem contexts.

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