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A STRUCTURED REVIEW OF COMPLEXITY IN ENGINEERING-PROJECTS

State-of-research and solution concepts for the plant manufacturing business

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─Abstract ─

The term ‘complexity’ has been present in academic discussion and industrial practice for many years. However, interpretations about its scope and content differ. While research focused on the product business, a common understanding and classification of complexity in the plant manufacturing industry are missing yet.

Based on an extensive literature review and various analyses, this contribution aims to describe complexity from the perspective of plant manufacturing business.

We found out that the differentiation of the dimensions multiplicity, variance, changeability and ambiguity, as well as elements and interactions seems to be an appropriate and suitable approach to structure complexity in an engineering context. Further this contribution identifies causes and illustrates consequences of complexity for a plant manufacturing company aiming for a better understanding of complexity in the plant manufacturing business.

Key Words: *standardization, research activities, systematization*

JEL Classification: M20

1. INTRODUCTION

1.1. Motivation

The term complexity is frequently used in various disciplines such as biology, sociology or the field of business administration in a variety of ways. Each discipline has its own definitions and interpretations (Richardson & Cilliers 2001)(Schmieder & Thomas 2005).

In business management and engineering, the complexity phenomenon receives great attention since the early 1990ies. Research concentrated on physical goods first, later complexity of internal and external processes became the subject of study (Bruhn et al. 2009). However, in both cases research focused on the product business particularly - the plant engineering business, which differs significantly from industrial plant business regarding to the complexity of the solution and amount of output, has not been subject of intense studies yet (Wagner & Löwen 2009). Nevertheless literature identified the challenge of increasing complexity in this field too (Schmieder & Thomas 2005).

The complexity of products, systems and organizations is seen as a major challenge for companies in the industrial plant business (VDMA 2010). Companies in this business usually try to avoid complexity in their organization since it requires significant management effort and hinders the effective control of product variants and processes.

This contribution analyzes complexity especially from the perspective of plant engineering business. Besides an overview of existing research in academic research and industrial practice, the questions if and to what extent research results from product business can be transferred to plant engineering business take up a central position in this study.

1.2. Plant engineering business

The plant manufacturing industry is characterized by its diversity. Companies provide engineering, construction and service of industrial - especially large-scaled - plants for e.g. petroleum refining, chemical processing, iron and steel processing or power generation and transmission. Orders are processed in the form of projects (VDMA 2010)(Löwen 2005).

Plant manufacturing companies work in a dynamic environment. They are challenged by competition, customer and investors to reduce costs and development time while meeting increasing expectations on quality. A key characteristic of industrial plants is the integration of components and systems delivered by suppliers and contractors. A solution is developed specific to the customer's requirements in a customer project. However, this system is technically understood in principle and is not 'first-of-its-kind'. Finally, the realization of a system requires integration of different disciplines like civil, mechanical or electrical engineering (VDMA 2010)(Löwen 2005).

A key discipline in this business is engineering, i.e. all technical-oriented services, processes, and working appliances needed to realize a customer specific solution ranging from definition, concept, implementation, to commissioning of an industrial plant (VDMA 2010)(Löwen 2005)(Smith 2002).

1.3. Methodical approach

This paper follows a theoretical research approach. A literature review gives an overview of the current state of knowledge in the field of complexity. The fields of engineering and business management were the main sources of relevant literature.

Based on the literature and various analyses, the authors explored if and how existing classification approaches which focused mainly on the product business can be applied for the project business of industrial plant engineering.

2. STATE OF RESEARCH

2.2. Definition of complexity

The term complexity has its origin in the Latin term 'complectere' which means 'to embrace' or 'to consist of'. In general complexity means that the overall behavior of a system cannot be described exhaustive, although there is comprehensive knowledge of its components and their interaction (Pratt et al. 2005).

The modern systems theory illustrates various complex phenomena using system models. In this contribution we base ourselves on the proven insights of systems theory to describe complexity in a technical and economic context. According to this theory complexity is primarily determined by the number of elements in a system and the interaction between these elements. Further the variation of these elements and their interactions over time is considered (Ulrich & Probst 1991)(Reiß 1993).

The term 'system' can interpreted in a number of ways. In industrial practice it usually refers to a technical solution, i.e. a technical system such an industrial plant consisting of various subsystems and components. In this contribution we explicitly want to consider organizational aspects (resources necessary to design and realize a solution: e.g. trades, IT-tools), too. So, the term 'system' in this study corresponds to an engineering project, consisting of technical and organizational aspects.

Researchers agree that a single, comprehensive definition of complexity is neither reasonable nor desirable. As a consequence multi-dimensional approaches are used to define 'complexity' (Giessmann 2010)(Bruhn et al. 2009).

2.2. Dimensions and types of complexity

Two popular multi-dimensional classification approaches for complex systems have been developed by Reiß and Ulrich & Probst.

According to Reiß four dimensions of complexity exist. These dimensions have certain forms for the elements of a system and their interactions. The dimensions and their expressions finally result in four types of complexity (Fig. 1)

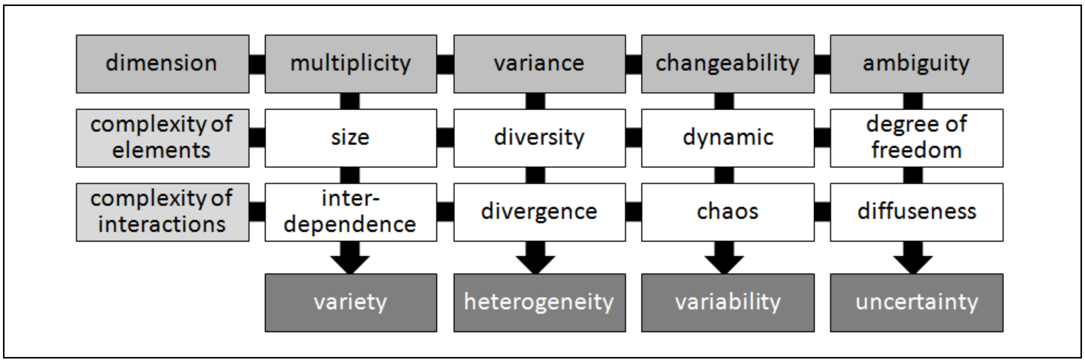

Fig. 1: Dimensions of complexity (Reiß 1993)

Multiplicity describes the number of distinguishable elements and interactions in a system. The **size** addresses the number of elements (e.g. products, components, suppliers), **interdependence** refers to the intensity of interactions (e.g. number of transactions with suppliers) between the elements. The number and interdependence both determine the **variety** of a system (Giessmann 2010)(Reiß 1993).

The dimension **variance** describes how many different elements and interactions exist in a system. If there are only minor differences between variants (e.g. different colors), a system is still manageable. But if the degree of variation increases (different materials, functions, etc.), complexity of the system increases strongly. In this context **divergence** describes the diverseness of the relations, while **diversity** refers to the elements. They both result in the **heterogeneity** of a system (Giessmann 2010)(Reiß 1993).

The previous dimension only considered a system in a static state, i.e. the system does not change its state over time. The following two dimensions consider the dynamic issues, i.e. the stability of the structure of a system over time.

Changeability describes the change or fluctuation of conditions, elements or interactions over time. **Dynamic** refers to the change of the elements, i.e. if it occurs constantly or disruptive, while **chaos** refers to the interactions. Together they determine the **variability** of a system (Giessmann 2010) (Reiß 1993).

Finally, **ambiguity** states that the perception of complexity of a system is subjective. The **degree of freedom** of the elements and the **diffuseness** of interactions lead to **uncertainty** (Giessmann 2010) (Reiß 1993).

Ulrich & Probst distinguish four types of systems dependent on the number of system elements and their behavior over time. Complexity in this context is defined as the ability of a system to take up a large number of different states over time (Fig. 2).

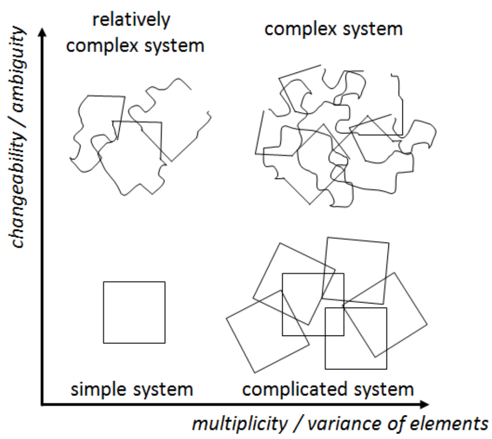

Fig. 2: Types of systems (Ulrich & Probst 1991)

Complicated systems are characterized by a large number of elements and interactions. They are similar to simple systems, but consist of comparatively more elements. In industrial plant engineering complicacy in a technical context is determined by the number of components and subsystems of a plant. In an organizational context it is characterized by number of stakeholder, trades, suppliers etc. In contrast to complex systems the patterns are still relatively stable over time (Ulrich & Probst 1991).

For complex systems it is not only their structure which is complicated; also their state is constantly changing (Ulrich & Probst 1991). In industrial practice this could be changing customer requirements, project teams or suppliers.

Relatively complex systems have fewer elements than complex systems and their structure can be described comprehensively. However, due to the high dynamic, their behavior is not predictable (Ulrich & Probst 1991). Engineering projects can be identified with complex systems, since they have a large number of elements and interaction as well as a certain dynamic over time.

2.2. Causes of complexity

Complexity in an organization can have a number of internal and external causes (Fig. 3). External drivers are caused by market and society. However, the manufacturer cannot influence these external drivers (Giessmann 2010).

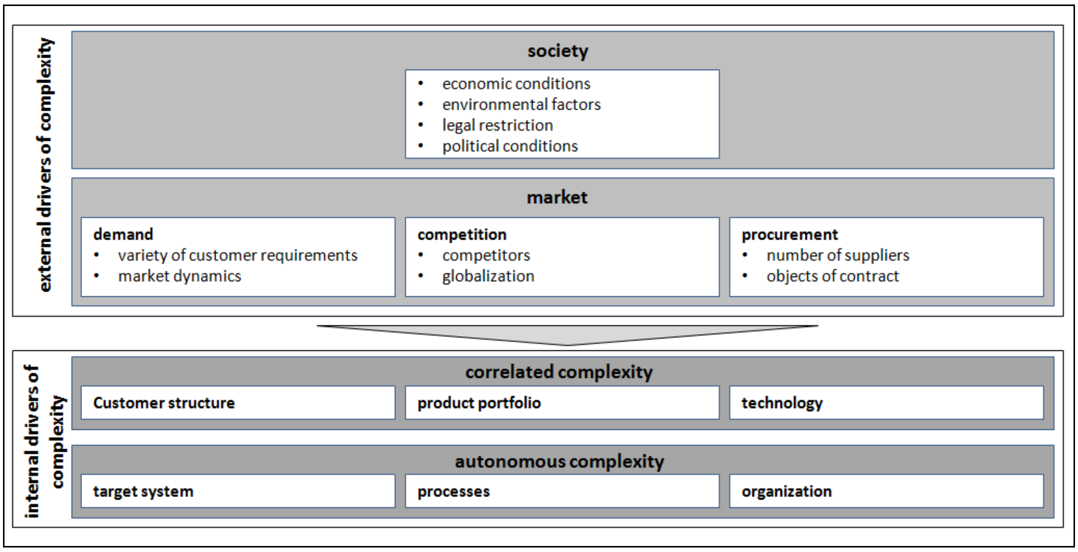

Fig. 3: Drivers of complexity (according to Giessmann 2010)

The external complexity results in internal complexity (Giessmann 2010)(Schmieder & Thomas 2005). Manufacturers have to provide variants of a plant solution to satisfy customer needs. The internal complexity can be differentiated in autonomous and correlated complexity and can be influenced by the enterprise itself. Correlated complexity is influenced directly by the external complexity. The autonomous complexity of an enterprise is not influenced by external factors, its causes lie in the structural and organizational conditions and processes of the enterprise itself (Bliss 2000).

2.3. Consequences

Complexity usually is not desired by plant manufacturers since it causes increased effort for management and controlling of product variants and processes. This in turn causes additional costs along the complete value chain (Schmieder & Thomas 2005).

It is generally accepted that too complex enterprises cannot be competitive in a market in the long term, since they are not able to satisfy increasing customer requirements for high-quality products, shorten delivery times and to fulfil high service standards.

3. COMPLEXITY IN PLANT ENGINEERING BUSINESS

After the general structure of complexity has been presented in clause 2, this chapter gives practical examples of elements and interactions in plant engineering projects (Tab. 1).

Tab. 1: Elements and interactions in engineering projects (not exhaustive)

dimension	multiplicity	variance	changeability	ambiguity
complexity of elements	• components • subsystems • project stakeholders • suppliers • trades	• materials • functionalities • solution variants • IT-systems • customers	• laws • new materials • new technological processes	• unclear requirements • different expectations of stakeholder (quality, costs, …)
complexity of interactions	• number of interfaces between components • intensity of cooperation between suppliers, trades	• International cooperation • Intercultural cooperation • Interdisciplinar y cooperation • data formats	• globalization • fluctuation of suppliers • fluctuation of employees • changing customer requirements	• regional/cultur al particularities

Elements of an engineering project can be of technical nature such as components, materials and functionalities, or of organizational nature such as suppliers, trades, customer segments etc. Hybrid forms like technological processes also exist. Interactions describe the relations between these elements and are mainly characterized by the intensity and number of interactions.

4. COMPLEXITY MANAGEMENT APPROACHES

Complexity management is the systematic development, design and control of complexity issues in an enterprise. It aims to achieve an optimum level of complexity along the value chain, creating maximum benefit for the customer with maximum efficiency for the plant manufacturer (Schuh 2005, S. 36).).

In contrast to variant management, complexity management is a more holistic approach. Variant management focuses only on the variety of (physical) product variants. Complexity management instead also considers e.g. processes and services (Schuh 2005, S. 36).).

Literature usually differentiates between three basic approaches of complexity management (Homburg und Daum 1997; Wildemann 1998) (Tab. 2).

Tab. 2: Complexity management approaches
(Giessmann 2010)(Kersten et al. 2004)(Lindemann et. al 2009)

approach	description
Avoid complexity	Prevent complexity in early project processing phases
Reduce complexity	Reduction of existing complexity by the simplification of processes and product variants.
Control complexity	Better management of existing complexity e.g. through it support systems.
Transfer complexity	Use of modular solution architectures. Complexity is transferred into modules. Thus, complexity out of system´s perspective can be reduced.
Postpone complexity	Differentiation of a solution for a specific customer is postponed until the latest possible point in the supply network.

All complexity management approaches aim to decrease internal complexity. But it is also important for plant manufacturers to maintain a certain level of complexity which is perceivable by the customer. This complexity is necessary to meet the individual requirements of the market (Giessmann 2010)(Lindemann et al 2009).

5. CONCLUSION AND OUTLOOK

This contribution gives an overview on existing classification approaches for complexity. It transfers research insights from the product business to the plant engineering business, a research field which has not been subject of intense studies yet. The differentiation of the dimensions multiplicity, variance, changeability and ambiguity as well as the breakdown of a system in elements and interactions seems an appropriate and suitable approach to structure complexity in an engineering context. This structure helps plant manufacturers to develop their own concepts in order to manage complexity in their organization systematically.

The management of complexity is already a major challenge in this business field. There are indicators that its importance will further increase in the near future. Technological change, globalization, individualization of customer needs and increasing environmental standards are only some trends which have influence on plant engineering business (Aerni 2004)(VDMA 2010).

In addition, the engineering itself becomes more and more complex. Globally distributed engineering activities increase organizational complexity. On a technical side, the number of components increases exponentially, so does the share of mechatronic and software components. Plant manufacturers are forced to offer a broad portfolio of solution variants, while individual customer requirements oppose to the reuse of components, solutions or processes (Aerni 2005)(VDMA 2010).

So called standardization programs may offer a solution for these problems. They integrate several complexity management approaches and support the reuse of components and processes. On a technical side they enable plant manufacturers to produce individual plant solutions built of standardized modules. A harmonization of processes and IT-support systems can help to reduce the complexity in the organization.

For further research, we suggest to add further detail to complexity management approaches in plant engineering. Such approaches are already implemented in industrial practice. The systematic improvement of these measures will be subject to more intensive studies in the near future.

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