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COMPLEXITY MANAGEMENT IN PLANT ENGINEERING

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ABSTRACT

Complexity is a major challenge in plant engineering projects. Participants in German plant engineering industry experience delays, cost overruns and stakeholder deception in complex projects. Literature on complexity management only deficiently considers specifics of this industry and lacks empiric insight. This paper analyzes how complexity is perceived in this industry and gives guidance to the improvement of complexity management. Therefore, a literature study and an expert survey have been conducted. Six underlying problem clusters can be distinguished: uncertainty in methods, requirements problem and uncertainty in goals, interfaces, systems thinking, process transparency and communication, and non-holistic complexity management. As a two-step approach, the application of systems engineering with its processes as described in the International Standard ISO 15288 and a complexity management process based on the Deming Cycle are proposed for treating the obtained clusters.

Keywords: complexity management, plant engineering, survey, construction

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1 INTRODUCTION

With an annual turnover of 200 billion Euros and 931 thousand peopled employed the German mechanical engineering sector is one of the most important economies in Germany (VDMA 2012). The engineering industry comprises plant, facility and infrastructure engineering, design and construction (abbr. plant EDC). With increasing automation und inter-connectivity, plants and facilities have been and still are becoming more complex. According to Baccarini (1996, p.201), "the construction industry has displayed great difficulty in coping with the increasing complexity of major construction projects." Coping with complexity requires a deep understanding of what complexity means in plant EDC.

2 SITUATION

Participants in plant EDC often experience problems in all of the three dimensions of projects success: delays, cost overruns and stakeholder deception, a fact proven by Flyvbjerg (2005) for Large Infrastructure Transportation Projects, stating that that applies for other project types, too, and giving several examples.

The products in plant EDC are highly complex: they are individual, unique facilities, engineered, designed and constructed for one special purpose and only once. With increasing complexity of the material product due to new technologies (esp. IT) the complexity of the projects to build them has to increase, too (Williams 1999). Furthermore, products of plant EDC projects are usually not consumer but capital goods. They are often critical for the buyer to maintain capable of producing wealth or fulfill his duties. In a 2011 study about success factor of competitiveness manager of plant EDC companies stated that competition had become more intense. Especially Chinese companies challenge established German and European ones with low prices and high tolerance of risks (VDMA 2011, p.1). Established companies react by increasing individualization and hybrid value creation. The strategy is changing from "product-centric" to "customer-centric" (Galbraith 2002). Market players try to offer not only customer fitted products, but also complete solutions including services like consulting, operation or maintenance. Those product service systems have to be newly developed for every contract, and so are the projects for their development. Their development comprises multiple domains like hardware, software and service development (Berkovich et al. 2009, p.727f).

Another particularity of the engineering industry is that there are several parties and disciplines involved in one project. These roles comprise not only vendors and customers, but other roles like operators, consultants and contractors or several stages of sub-contractors. For the management of engineering projects a temporary multi-organizational structure is created (Baccarini 1996). Therefore, engineering and construction projects are considered to be highly complex and even unmanageable systems (Wild 2002).

3 OBJECTIVE

The objective of the research is to analyze how complexity affects plant EDC projects and to give guidance to improvement of complexity management in the plant EDC industry. A lot of research has been conducted concerning complexity issues in organizations and other industry fields like logistics or services (Blockus 2010).

The first research question has been to investigate what "complexity" means in the field of plant engineering and what forms are significant. Blockus (2010, p.32f) claims that there are four major deficits in business administration literature concerning coping with complexity: conceptual, methodological and empiric deficits. Contradicting statements (no. 1) belong to conceptual deficits. Complexity is treated in two ways. One view is that complexity should be reduced as far as possible and the remaining part has to be managed. The other view follows Ashby's (1964) "law of requisite variety" saying that coping a complex situation requires a certain degree of complexity. The other conceptual deficit is a lack of consideration of the specifics of the services industry; that argument also applies to the engineering industry (no. 2). The methodological deficits are the lack of appropriate measurement and evaluation of complexity which is prerequisite for an effective management of complexity and of corresponding methods (no. 3). The empiric deficit in literature is the lack of empiric insight (no. 4). Knowledge about which types of complexity and what drivers for complexity

are important for a certain industry enables target-oriented decisions about how complexity has to be designed (Blockus 2010, p.31ff).
Baccarini (1996) also states that it is important to be clear about the type of complexity that is dealt with, what most project management literature fails to do. It is agreed on in management practice that the forms degree of complexity determines tools and methods are used, i.e. how the project is managed (Baccarini 1996, p. 201). Galvano and John (2004) state that "modern complexity poses a major challenge […] [and] must be understood, predicted and measured" to successfully engineer complex systems. This paper intents to fill the mentioned gap. The first objective is to find out what types of complexity are important in the German engineering industry, thus ameliorating the deficits No. 2 and 4. As a second objective, we want to give guidance for coping with complexity.
Systems engineering (SE) and the international standard ISO 15288 (2008) offer a framework that has been developed to cope with complexity. As a third aim, we want to show how that common process framework might improve cooperation and communication in complex plant EDC projects.

4 APPROACH

The objective was approached as follows: A literature review was conducted to obtain profound knowledge of diverse definitions of types of complexity and the state-of-the-art strategies and methods for handling complexity. Based on the literature review and the problems that practitioners had reported, five hypotheses have been formulated:

1. Complexity in plant EDC is not acquired and modeled
2. Complexity is not evaluated
3. Complexity management is not holistic
4. Systems Engineering standards are not being applied
5. Improved complexity management can alleviate the experienced problems

A non-representative expert survey has been conducted. On a first level the experts were clustered in contractors, operators, consulting planners and plant installers, depending on a) the company they work for and/or b) the position they hold. Consulting planners have then been clustered again in management, development and quality, depending on their position. Plant installers have been divided following generic business departments: procurement, engineering, production, quality, management and sales. The development (planners) respective engineering (installers) group has then been split up in two sections. The experts were chosen randomly from engineering companies listed on the VDMA website. The questionnaire was reviewed and pre-tested. The first contact was established by phone, including a brief presentation of the project. Then the questionnaire for the corresponding target group was e-mailed. The questionnaires consisted of target group specific questions concerning what methods of complexity management and Systems Engineering are applied, what standards are prevalent in the industry and how important different complexity types are. The questions could be answered on a Likert scale of four items from either "not agreeing", "not at all prevalent", "no potential" or "no influence" (1) to either "totally agreeing", "very prevalent", "very high potential" or "very high influence" (4). The results are given by the arithmetic mean (AM) of the answers.
Only exception is the part of the complexity forms: Since they could not been inquired directly the experts were asked to rate the influence of their respective drivers. For the interpretation the average of the arithmetic means (AAM) of the drivers of a certain complexity form was used as the result for the complexity form. 18 types of complexities have been identified by previous studies (see Figure 3). Each type is driven by specific complexity drivers. In this survey a total of 119 drivers were tested for relevance. Each complexity type is usually driven by the number, variety, interdependences and the dynamic or variability of its elements (Blockus 2010). For further reading and description of complexity types and drivers also see Lasch & Gießmann (2008), Kirchhof (2003) and Blockus (2010). Subsequently, the results have been grouped to six clusters according to their root cause. Clusters are sets or groups of objects with similar description or characteristics (Romesburg 2004).

5 LITERATURE REVIEW COMPLEXITY: DEFINITIONS, TYPES AND DRIVERS

Literature research showed that there is no standardized definition of the term "complexity" or "complex project" and what is meant by it (Williams 1999). Blockus (2010) distinguishes four aspects of complexity in business administration:

1. Constitutive characteristics. Definitions of complexity usually consist of number and variety of elements and relation between elements, as well as the dynamic or variability of elements and relations (cf. McFarland 1969).
2. Reference objects. Complexity of a system (a system of systems) is determined by the definition of its boundaries and affiliation of elements to the considered systems (of systems to the considered system of systems)
3. Forms of complexity. Two forms of complexity can be distinguished: Objective and subjective complexity (cf. Kirchhof 2003, p.15: structural and functional complexity). Objective complexity is related to the constitutive characteristics. Subjective complexity however means the complexity that is perceived by persons interacting with or within the system.
4. Effects of complexity. Complexity can lead to differentiation from competitors, but can also lead to cost. It has to be noted that these costs are considered irreversible (Blockus 2010, p. 25).

Williams (1999) describes project complexity as a combination of structural complexity (i.e. differentiation or the number of varied elements and interdependency or connectivity) following Baccarini (1996) and the uncertainty in goals and means following Turner & Cochrane (1993).

Hertogh & Westerveld (2009) investigated complexity in Large Infrastructure Projects (LIPs) or “megaprojects” in Europe. They found the same two characteristics of complexity in a literature review: Detail complexity, which is defined as “many components with a high degree of interrelatedness” (cf. structural complexity) and dynamic complexity which can be distinct by “the potential to evolve over time” and “limited understanding and predictability” (i.e. uncertainty)(Hertogh & Westerveld 2009, p. 187).

Dehnen (2004, S. 31) proposes two main criteria for complexity: the first criterion is the number and interconnectivity of system elements (what is called structural or detail complexity above), the second criterion is dynamics and variance of the elements and their behavior. Thus dynamic makes the difference between complicated and complex systems: the high dynamic of change typifies a complex system. Complicated systems however are stable for a certain duration (Lindemann et al 2009, p. 25).

6 KEY FINDINGS

Survey responses

In this survey 65 questionnaires have been sent out to experts, of which 41 have been returned, thus giving a respond rate of 63 %. Most of the experts are more than 50 years old (54 %, 40-50yo: 34 %, 30-40yo: 7 %, 20-30yo: 5 %) and have an average professional experience of 22,8 years. They comprise General Managers (12 %), divisional managers (29 %), department managers (41 %) and project managers (10 %).

Their companies are mostly medium and big companies: 59 % of the respondents work in companies with an annual turnover of more than 50 million Euros, 20 % in companies with 10-50 million Euros and another 12 % in companies with 2-10 million Euros annual turnover. 7 % of the experts work in companies with 10-50 employees, 37 % in companies with 50-250 employees and the majority of 59 % in companies with more than 250 employees. As a first result shown in Figure 1, it can be stated that the experts are well aware of the problems concerning cost overruns. 41 % of the respondents estimate that significant cost overruns occur in 20-50 % of all projects (see Figure 1 ‘Projects with cost overrun’). 15 % of the experts go further, saying that costs are overrun in 50-80 % of cases. Nevertheless, average cost overruns are estimated by 73 % of the respondents to be between 10 % and 30 % of the prospected costs, as shown in Figure 1 (‘Average cost overrun’).

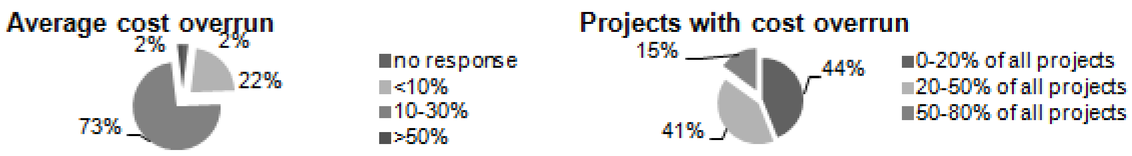

Figure 1: Cost overruns

Cluster 1: Uncertainty in methods

The first key finding is that there is an existing need for a standardized and holistic process model. Relevant standards seem to be either not common or not known. 57 % of the respondents stated that the Systems Engineering standard ISO 15288 is not or rather not common (AM 2,04, see Figure 2 ‘Standards’), while 23 % did not respond to the question. The standard VDI 2221 (1993) by the Association of German Engineers (Verein Deutscher Ingenieure, VDI) that proposes another process model was rated (rather) not prevalent by 47 % of all respondents (AM 2,09), with 30 % of the experts who were asked this question did not answer. The only model that seems to be widely used is the one introduced in the Official Scale of Fees for Services of Architects and Engineers (German abbr.: HOAI) with an AM of 3,08.

Following the vast majority of the experts no important reasons hinder the use of frameworks and reference models (AM 1,89, see Figure 2 ‘Frame model potential’). If anything, significant cost reductions can be realized (AM 2,93) by using standardized frameworks and reference models, according to 73 % of the respondents.

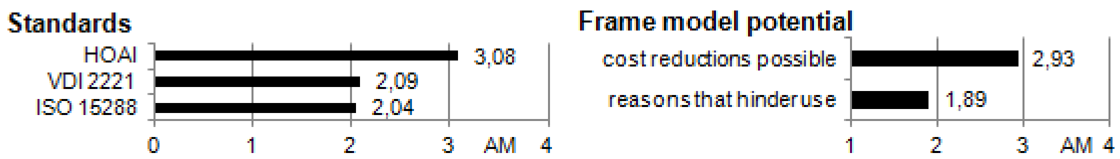

Figure 2: Prevalence and potential of standards and frame models

Cluster 2: Requirements problem and uncertainty in goals

The uncertainty in goals can be traced back to the problem of assessing and managing requirements or requirements engineering. This leads to two statements: (1) Different issues that are regarded to be complex actually add complexity to the requirements, and (2) the way of handling requirements is the root cause for other problems.

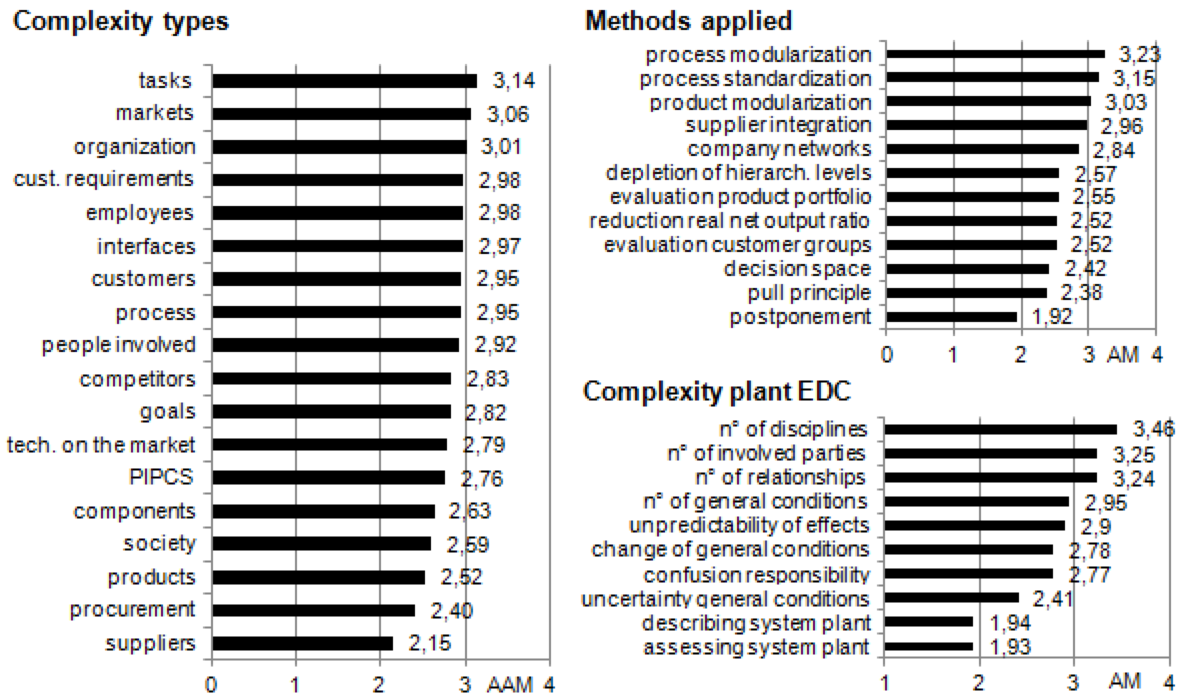

Figure 3: Complexity types, Methods applied and Complexity in plant EDC[1]

Statement (1) is the case for new, various or changing markets (AAM 3,06), customer groups (AAM 2,95), and customer requirements (AAM 2,98) that cause new, various or changing requirements. This also applies to number, change and uncertainty of general conditions (AM 2,95/2,78/2,41 respectively, see Figure 3 ‘Complexity plant EDC’). As to general conditions, complexity is rather seen in their respective multitude than in their change or uncertainty. This leads to the assumption that the modeling of general conditions is the bigger problem than their management.

[1] PIPCS… Project information, planning, controlling and supervising system

Other complexity forms like competitors (AAM 2,83) and technology on the market (AAM 2,79) are just slightly above average. In case of the competitors it is mainly the prices that lead to complexity (AM 3,15). Those complexity forms can be expressed in additional requirements, too, like additional cost or technological requirements.
The management of requirements does not seem to be well established. The accordance to statements concerning requirements management was only medium compared to others. Among those statements verifiability (AM 2,94) and the capability of systematic assessment of the requirements (AM 2,95) are ranked highest, followed by the capability of assessment of interdependencies (AM 2,97) and the traceability of changes (AM 2,83). As for strategic assessment, the result can be interpreted to represent rather the aspiration: Society as a form of complexity does not seem to have great influence (AAM 2,59). Among its drivers it is basically economic factors and the multitude of regulations that are regarded as influential rather than politics, cultural factors and the change in moral factors (see also cluster 4 for stakeholder integration).
The complexity of goals and goal conflicts (AAM 2,82) is very probable an effect of conflicting interests of stakeholders (AM 2,95). The latter can be put down to the lack of a process that handles conflicting requirements. Further literature review supported that finding: according to Berkovich et al. (2009, p.734), there is no approach of requirements engineering that is designed for the needs of systematic development of product service systems in literature.

Cluster 3 Interfaces and structural complexity

This cluster represents the structural complexity of plant EDC projects. Like cluster 2 could be traced back to requirements, the structural complexity of plant EDC project can be traced back to interfaces.
When asked about what complexity exists in the field of plant EDC, most experts responded that it is the number of disciplines involved in a project (AM 3,46), closely followed by the number of involved parties (AM 3,25) and the number of relationships among involved parties (AM 3,24, see Figure 3 ‘Complexity in plant EDC’). Confusion concerning responsibilities was also mentioned to be a driver of complexity (AM 2,77). The latter can be linked to the management of interfaces, since responsibilities are delimited at interfaces. Also, “interfaces” was the only issue that was specially mentioned when asked about what else adds complexity to plant EDC.
Regarding complexity forms “people involved” (AAM 2,92), ”employees” (AAM 2,98), “organization” (AAM 3,01) and “interfaces” (AAM 2,97) are all in the more important half of all complexity forms. Components that add complexity to technical interfaces does not seem to be considered as very influential (AAM 2,63, see also cluster 4).
All those forms and drivers add complexity to interfaces: many and different involved disciplines lead to interfaces between those disciplines, organizational complexity leads to interfaces between organizational sites and departments, the complexity of employees and people involved means an increased need for coordination which is conducted at interfaces.

Cluster 4: System thinking

What stands out is the inferior role the plant as a system represents in terms of complexity. The experts rated the difficulties of assessing and describing the plant as the least important influence on the complexity of plant EDC (AM 1,93/1,94). The complexity of products (AAM 2,52) and components (AAM 2,63) were also rated under-average concerning their influence on complexity. This can be interpreted as a lack of systems thinking when it comes to solutions: Seeing the system “plant” (or the products and components) as part of the solution to the stated problem, it does not seem to be complex. If the plant was considered as a part of the problem space it would have been rated very probably as more influential on complexity, since the system “plant” comprises all the other issues that are considered to be complex.
Procurement-related issues like the complexity of procurement (AAM 2,40) and the complexity of suppliers (AAM 2,15) are generally rated as being little influential. There are two possible explanations for that effect: First, one could assume that companies in plant EDC reached sufficient supply chain management. Having a closer look it shows that the responds from procurement department rated the procurement complexity higher. It is the engineering department who does not seem to consider procurement to add complexity. This represents another indication that thinking in the engineering industry is not sufficiently holistic and system-oriented.

Further indicators are that the deposal or renewal of the plant is not part of the design of the plant in the first place (no holistic life cycle view) and that not all stakeholders are taken into consideration. Results show that society as part of the system environment does not participate in the design process. That matches with the little influence society has on complexity as mentioned above. The question occurs how society's requirements are represented in project. Surprisingly the investor is not importantly involved in the design process, either. Apart from regulations it is also questionable how public authorities' interests are factored in. Tendering and submission are not characterized by system orientation either: tenders are mostly not composed by (sub-)system but by discipline.

Cluster 5: Process Transparency and Communication

The fifth key finding is the existing need for inter-organizational process transparency and new means of communication. The statement concerning inter-organizational process transparency has the lowest agreement among the experts (AM 2,71). Tasks and especially their heterogeneity seem to add complexity (AAM 3,14, see Figure 1 'Complexity types'). It may be the increase of process complexity (rated AAM 2,95) that leads to this variety of activities. The complexity of the project information, planning, controlling, and supervising system is rated a little less, with an AAM of 2,76.
Defined and transparent processes can also help overcoming personal differences between involved persons (AM 2,64) and decrease the number of persons who seem to be overwhelmed (AM 2,87), two drivers for complexity that are considered to be influential, too. Effects of actions that are currently unforeseeable (AM 2,90, see Figure 3 'Complexity plant EDC') can partly become predictable by using process models.
Misinterpretations are an impact of a lacking common basis for communication. As a driver for complexity, misinterpretations are regarded as quite influential (AM 2,84). The importance of interfaces as described in cluster 3 also increases the need of communication.

Cluster 6: Non-holistic complexity management

Results show that complexity management is not universal and consistent. The term of complexity is not defined by the majority (about 68 %) of the participating companies of the engineering industry. Basis for further handling of complexity is its acquisition, modeling and visualization (Lindemann et al. 2009, p. 31FF; Maurer 2007, p. 37). When asked about whether complexity is systematically assessed the vast majority of the responding experts disagreed, regardless of the form of assessment, be it by key figures (AM 1,66), costs (AM 2,08) or models (AM 1,72), as illustrated in Figure 4 ('Assessment'). The next step is the evaluation of complexity. Activity based costing is considered to be the central approach to evaluation of cost effects of complexity. However, Figure 3 shows that evaluation of complexity is not common, neither according to customer needs (AM 1,82), nor according to costs (AM 2,32).

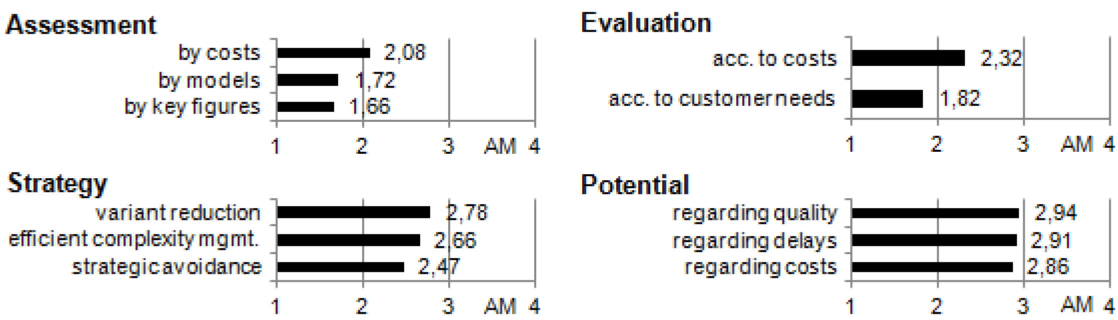

Figure 4: Complexity management

Concerning strategies in coping with complexity, three basic strategies are distinguished in literature: Reducing the existing complexity on short term, efficient managing of non-reducible complexity on mid-term and preventive avoidance of newly developing complexity on long-term.
The dominant strategy in dealing with complexity seems to be its reduction by reducing variants. 56 % of the respondents mention it to be applied (AM 2,78, as shown in Figure 4 'strategy'), while 52 % say that the focus is (also) on efficiency in handling remaining complexity (AM 2,66). Only 44 % of the respondents state that complexity is being avoided by strategic measures (AM 2,47).

Literature offers a lot of methods and approaches to cope with complexity.[2] Figure 3 ('Methods applied') lists some of them non-exclusively and shows the results. When it comes to the appraisement of the prevalence of different methods process modularization (AM 3,32) and standardization (AM 3,15) and product modularization (AM 3,03) are mentioned as most prevalent. On the other hand measures like evaluation and adjustment of customer groups (AM 2,52) and the product portfolio (AM 2,55), the increase of decision spaces on lower hierarchical levels (AM 2,42), depletion of hierarchical levels (AM 2,57) or the reduction of the real net output ratio (AM 2,52) are not very widespread. On the supply side, supplier integration (AM 2,96) and the creation of company networks (AM 2,84) are considered to be commonly applied. This result might be an effect of the efforts in supply chain management the companies spent over the last years. Least common and known are processes that regulate themselves by implementing the pull principle (AM 2,38) and the postponement method (AM 1,92).
As a reason, and in coherence with the findings concerning strategies of complexity management, it is assumed here that the firstly mentioned measures take action on an operational level, while the latter measure have to be conducted on a strategic one. This stands in contrast to the postulation by Blockus (2010, p. 271) who sees complexity management as being a part of strategic management. The experts estimated the potential of complexity management very high (see Figure 4 'potential'), regarding all three dimension. The potential for improvement regarding quality is ranked highest (AM 2,94), followed by improvements regarding delays (AM 2,91) and regarding the reaching of cost targets (AM 2,86).

7 SYSTEMS ENGINEERING AND HOLISTIC COMPLEXITY MANAGEMENT

The authors propose a two-step approach for treating the obtained complexity clusters: The first step on short- to mid-term range is the application of selected methods of systems engineering to plant EDC projects encountering clusters 1 to 5. As a second step the implementation of a holistic complexity management could be determined as an improvement of the problem stated as cluster 6.

Application of Systems Engineering

To respond to the need of a process models and methods as described in cluster 1 in section 5, the concept of Systems Engineering shall be introduced here. Plants and facilities are complex engineered systems which are –if regarded as such- designed by a systems engineering approach (Galvano and John 2004). As defined by the International Council of Systems Engineering (INCOSE 2011), "Systems Engineering (SE) is an interdisciplinary approach" as demanded in clusters 1 and 2 "and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements […][and] system validation […] with the goal of providing a quality product that meets the user needs", which is exactly what seems to be the problem of cluster 2. Cluster 3 is encountered by "design synthesis". "Considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal […][as well as] both the business and the technical needs of all customers" describes the systems thinking that is urged by cluster 4.
ISO 15288 (2008) states that the increase of complexity in systems has led to an increase of the challenges that system-creating organizations face. As one source of these challenges, it further mentions the "lack of harmonization and integration of the involved disciplines" (ISO 2008) which is the case in engineering projects. The International Standard satisfies "the need for a common framework to improve communication and cooperation among the parties that create, utilize and manage modern systems in order that they can work in an integrated, coherent fashion" (ISO 2008), what meets the needs of clusters 1 and 5.
Two key standards in this domain. The international standard ISO/IEC 15288:2008 describes generic processes, while the INCOSE Systems Engineering Handbook (INCOSE 2011) "further elaborates the processes and activities to execute the processes". SE processes and activities can be conducted formally or informally. The SE Handbook names four influencing factors that determine the appropriate level of formality for each project (INCOSE 2011, p. iv) which there are the need for communication across organizational borders and over time, the degree of complexity, the level of

[2] Those methods cannot be introduced in this paper. As a further reading see Kirchhof (2003) and Blockus (2010) who describe methods of complexity management and use cases.

uncertainty and the consequences to human welfare. Following the result of this survey, the first three of them can be regarded as given for plant EDC projects. Regarding these influencing factors SE activities in plant EDC are recommended to be rather formal. The processes "can add significant value in new domains if appropriately selected and applied" (INCOSE 2011). They comprise the tailoring process, since the generic processes have to be tailored to the specific needs of a certain project to find the appropriate degree of formality.

Daenzer and Huber (1994) present SE as a methodology of problem solving that consists of four parts: systems thinking and a process model build the SE philosophy, while system design and project management constitute the problem solving process. Table 2 shows how these fields can be applied to counter the problems described in clusters 2 to 5 and names examples of methods or processes in the ISO 15288.

Table 2. SE approach, methods and processes for problem clusters

Cluster	Problem	SE Approach	Example (ISO 2008; INCOSE 2011)
2	Requirements assessment and management	System Design: Problem and requirements oriented top-down approach	Stakeholder Requirements Definition Process Requirements Analysis Process Requirements Verification Traceability Matrix
3	Interfaces	Project Management: purposive sequence of activities and coordination of involved people	Project Management Processes (several) Interface Control Documents
4	Systems thinking	Principle of SE: problem oriented and holistic approach	Integration of all life cycle phases and stakeholders, separation of problem and solution
5	Process transparency and communication	Process model: Life-cycle-phases and top-down proceeding; documentation	Standardization of process and nomenclature Vee-Model as basis for communication Defined and documented processes

As described in section 5, complexity can be dissected in complicatedness (or structural complexity) and dynamic. Following this distinction, SE methods and processes can be distinguished by whether they handle complicatedness or dynamic and change. The methods and processes in Table 2 are considered to primarily deal with complicatedness. To cope with the dynamic component of complexity, SE offers processes like the change management process and configuration management process. They can be applied to all kinds of documents and other processes.

Holistic Complexity management

A lot of conditions influence complexity management. Generic recommendations cannot be given; the choice of measures depends on the specific company and the situation (Blockus 2010, p.269). The goal for handling internal complexity must thus be the implementation of a holistic complexity management process. Complexity can only be managed successfully if the corresponding measures are conducted on a repeating basis and on a strategic level. Lasch and Gießmann (2008, p. 115ff) propose a complexity management process that is based on the Deming cycle, in analogy to the quality management process, that has to be repeated continuously. The four process steps are:

Plan. Plan new products, services and processes with respect to complexity they are creating along the whole value chain. Methodological know-how is prerequisite in this step.

Do. Analyze the state of complexity by implementing key figures and identify complexity drivers and effects. Therefore, define complexity and its forms and drivers.

Check. Analyze and evaluate complexity drivers and choose the strategy for each form of complexity. Derive means and plan process adjustments.

Act. Improve the state of complexity. Establish conscience for complexity issues and training to change behavior. This phase has strategic character and has to be attended by management.

8 CONCLUSION

The results show that complexity is a important issue in the field of plant EDC. Diverse measures of complexity management are already applied. However, they cope with complexity inside of the companies. Furthermore, the application appears to be infrequent and on a non-strategic level. On the other hand, there seems to be a lack of methods that cope with the complexity of engineering projects.

As a first step in the research of complexity in plant EDC it could be shown what types of complexity matter for this industry with its specifics. A generic approach to the implementation of a holistic complexity management process on a strategic level based on the Deming cycle was given. Systems engineering methodologies and processes were revealed as possible approaches to handle complexity of plant EDC projects on a short-term view.

To further establish complexity management in plant EDC, it is recommended to conduct further research, especially regarding the assessment and measurement of complexity and the tailoring of SE processes to projects of plant EDC.

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