Measurement of Organizational Complexity in Product Development Projects

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Abstract—**Many modern products are becoming more and more complex in order to cope with customers' demands regarding performance and lifecycle properties. As traditional product development structures struggle to keep up with the rising complexity, companies may form cross-functional teams, integrate off-site experts or outsource certain tasks to external suppliers. This results in increasingly complex project organizations, requiring advanced management and coordination skills. Recent research has found a direct relationship between complex project organizations and missed cost and schedule targets, suggesting companies' inability to manage complex organizations.**

This paper develops a framework to measure organizational complexity and thus make it visible and more easily controllable for project managers. A broad literature analysis identifies a range of factors associated with organizational complexity. A mathematical model infers the complexity of a project organization based on the identified factors. A proposed visualization method identifies complexity hotspots, which can be used to assess project alternative structures. Finally, a project example illustrates the application of the overall method. Altogether, this approach may be useful to enhance project managers' awareness of complexity inside a project organization and thereby empower them to avoid overly complex, unmanageable structures.

I. INTRODUCTION

The competitive conditions for companies in industrialized countries have significantly changed over the past 30 years. These changes are often described by a transition from a seller's to a buyer's market. The customer side has become more and more demanding regarding product performance, lifecycle properties and individualization, leading to increasingly complex products [1][2]. The seller side has coincidently experienced growing international competition, primarily induced by the fall of the iron curtain and the subsequent globalization. The increased competition has forced companies to speed-up development of new products as well as develop and produce more efficiently [1][3].

To gain competitive advantage, the development process has become a critical success factor due to its central role in determining subsequent revenues and costs. Despite this central role, however, development projects often face severe problems, such as budget and deadline overruns or missed specifications [4]. A famous example is the Boeing 787 Dreamliner, which exceeded the estimated costs by three times and took roughly twice as long to develop as previously expected (see Figure 1).

An investigation of the reasons for this revealed that Boeing's missed targets were induced by an excessive growth of development project complexity. The product side became more complex due to the use of new materials (esp. composite fiber), with which neither Boeing nor its suppliers had sufficient experience. The organizational side became more complex due to a highly increased external development, outsourced system integration and greater interdependence through a more parallelized development process [5].

Insufficient ability to handle both growing complexities eventually led to the major project delay and skyrocketing costs, pushing Boeing into a major crisis [6]. It was later revealed that different voices at Boeing had warned of the high project risks but were ignored due to many managers having underestimated the complexity. Especially the organizational side had become excessively complex without the required ability to control and manage it.

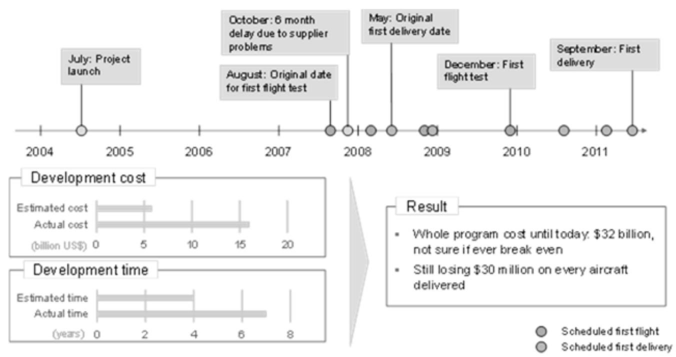

Figure 1: Industry example: Boeing 787 Dreamliner [5][6][7][8]

This example is representative of many other development projects, where estimated costs and development duration are exceeded. Although Boeing did overcome the crisis, each delivered 787 still generates losses [8].

Although complexity is not a bad thing per definition – complexity enables functionality and can thereby create customer benefit – excessive complexity and non-value driving complexity can seriously harm business operations by decreasing profits, reducing flexibility and dissipating energy [9]. Recent findings even postulate a nearly linear correlation between complexity level and the amount of cost overruns in development projects relative to the initial program estimate [10]. It is therefore a significant goal to be able to put complexity into perspective. *What are the benefits of more complexity and what are the costs?* Only if the benefits outweigh the costs, higher complexity in products and organizations should be accepted.

Businesses and research have started to perceive the importance of complexity research and quantifications. In recent years, considerable research on complexity has been conducted, examining complexity from different perspectives and research areas. Some contributions have even produced complexity measurements in order to assess the level of complexity in certain systems. However, many of the complexity assessments investigated only focus on very specific systems or aspects of complexity. Moreover, on the topic of organizational complexity, no objective and user-friendly measurement was found in existing literature. Given Boeing's problems with excessive organizational complexity and recent studies that identify organizational complexity factors to be project complexity's biggest contributor [11][12][13], this opens a very interesting topic for research. Despite the predominant opinion that projects usually fail due to overly complex products, it is important to understand that "projects fail on the people side" [14].

To understand the high potential benefit of an early complexity awareness and assessment, Figure 2 shows the accrued vs. the determined costs during a typical product development project. It becomes obvious that the majority of project costs are determined fairly early. With every development stage the possibilities of influence decrease, mostly in the first phases until the end of product development. At that stage, 85% of all the overall costs are already determined [15].

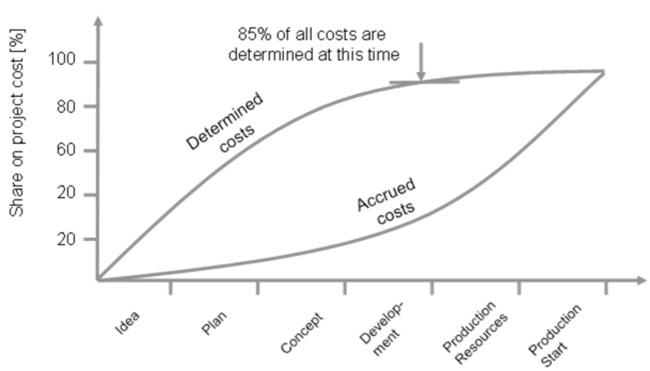

Figure 2: Accrued vs. determined costs in product development projects [15]

Anticipation of effects on later processes in the early project stages enables the timely identification of possible sources of error and potential for improvement. While corrections in early stages are easy to apply, later changes at the product or processes are linked to high costs.

But not only costs are a critical success factor of development projects. The time-to-market and in particular the resulting market entry timing play a critical role in product success and company revenues. Figure 3 shows the relationship between the market entry point and the expected revenues a product generates. Long product development (possibly caused by iterations in the product development process due to high complexity) does not only lead to higher development costs, it also has a direct influence on the cumulative revenues over the product lifecycle. This is due to the fact that an earlier product helps to build a customer base, skim premium prices in a monopoly and realize cost advantages by experience curves. A late market entry correspondingly has a negative impact on revenues [1].

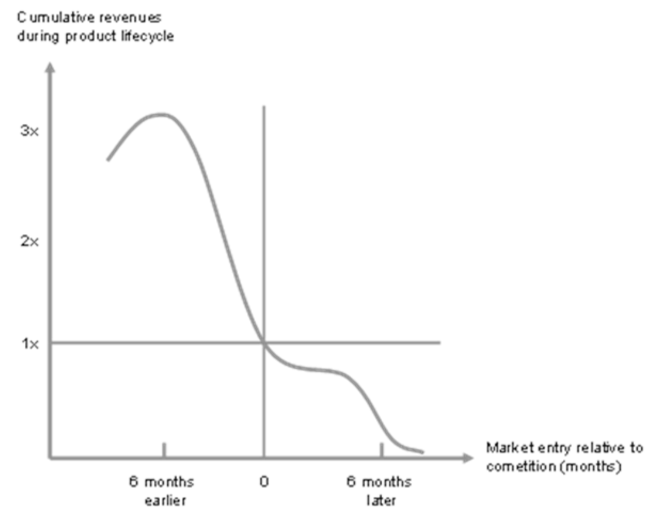

Figure 3: Influence of market entry on lifecycle revenues [1]

In order to link complexity and costs to evaluate the cost and benefit of additional complexity as well as reduce complexity in early development stages, one needs to have sound and objective complexity measures. Although companies are beginning to understand the importance of managing and measuring complexity, most estimates are based on subjective assessments and thus deliver specious results and result-based decisions [16].

The goal of this paper is therefore to develop a more objective organizational complexity measure that supports the early awareness of complexity and builds the foundation for subsequent complexity – cost linkages. This is achieved by the fulfilment of two steps: identification of major factors driving organizational complexity and the integration of these factors into a mathematical model and procedure.

The relevant factors driving organizational complexity are obtained in a first step by summarizing and combining the results of previous findings on factors driving organizational complexity. Knowing which factors contribute to complexity emergence already enhances complexity awareness. Incorporating these factors into a mathematical model in a second step allows the calculation of the overall organizational complexity present in a project organization. This supports the comparison of various project alternatives according to their complexity levels.

The paper therefore assists managing complex projects. Being aware of the factors driving complexity and the ability to compare various project alternatives may support project managers in avoiding overly complex projects.

II. ORGANIZATIONAL COMPLEXITY

"Any darn fool can make something complex; it takes a genius to make something simple." (Pete Seeger)

Before being able to identify factors driving organizational complexity or developing a mathematical model, a fundamental understanding of the topic has to be achieved. The following section helps to achieve this understanding and define organizational complexity for the context of this paper.

Current research has at least 30 definitions for complexity, underlining the necessity to refine organizational complexity for the following approach [17]. Organizational complexity is one of many research areas that results from the integration of the separate domains of organization and complexity. However, in some aspects it differs significantly from the other research domains so a focused and in-depth analysis is needed.

A. Definition

Complexity can be generally defined as a system feature and means interweaved, networked and connected [18][9]. A widely recognized definition by Ulrich & Probst describes complexity as the number, diversity and relationships of elements as well as system-inherent dynamics [19].

Regarding organizations, Backlund defines a complex organization as an organization whose behavior is complex, whose inner structure is complex or whose processes are complex [20]. Other approaches to define organizational complexity can be found in Lawrence & Lorsch, Thompson or Dess & Beard [21] who focus in heterogeneity and diversity, Milliken who concentrates on analyzability or Sharfman & Dean who take geographic concentration as a valid measure for organizational complexity [9]. Thompson depicts complex organizations as a set of independent parts, which together make up a whole that is interdependent with some larger environment [22].

Daft defines complexity in organizations as the number of activities within the organization, measureable by three dimensions: Vertical complexity, quantifiable by the number of levels in an organization hierarchy, horizontal complexity represented by the number of job titles or departments across the organization and spatial complexity expressed by the number of geographical locations [23]. Baccarini, whose definition is the basis for many works related to project and organizational complexity describes organizational complexity using the two dimensions differentiation and interdependence. Differentiation can either be expressed in form of horizontal differentiation (differentiation in organizational units and division of labor) or in form of vertical differentiation, referring to the depth of hierarchical structure [13]. Lane et al. see complexity in globalized organizations as a four dimensional concept consisting of the dimensions multiplicity, interdependence, ambiguity and flux [24]. Similarly, Steger's organizational complexity framework is constituted by the complexity elements diversity, interdependence, ambiguity and flux [25]. It can therefore be seen as an improvement upon the Ulrich & Probst definition at the beginning of this section.

Summing up the presented definitions and capturing all relevant aspects, a concept in line with the works of Ulrich & Probst, Lane et al. and Steger emerges. Diversity, interdependence and ambiguity are each difficult to control by themselves and an even bigger challenge if being combined. What makes the whole thing once again more challenging is that each of them is constantly shifting. "The entire network of complexity is in a constant state of flux." [24]

The overall framework which will be basis for this paper is illustrated in Figure 4. In order to achieve an equal understanding of these four dimensions, each one will be briefly explained.

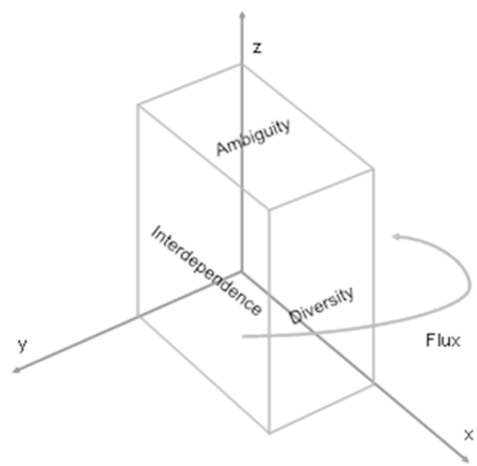

Figure 4: Four dimensions of organizational complexity framework

Diversity

Diversity is defined as the plurality of elements and comprises the physical and structural elements of organizations as well as their environment. As one of the key elements of complexity its understanding is decisive to understand the concept of complexity [9].

Plurality of elements encompasses two components: The number of elements (multiplicity) and the dissimilarity of elements (variety). Research has found that complexity is directly linked to these two. A higher number of elements increases complexity while complexity also rises with the variety across elements [26]. Diversity is a very important component of systems as it determines the ability to incorporate a certain number of different states in a given time span [9].

Interdependence

Interdependence is used to describe a link or influence of different sorts between entities [27]. In organizations it is often equated with interactions between entities [28]. Others define it as the influence one entity has on another [29].

Generally it can be stated that complexity increases with the degree of interconnectedness among elements [30][31]. According to Fiss, organizations can be perceived as clusters of interconnected structures and practices, which stands in contrast to viewing them as loosely coupled, modular entities that can be investigated solely [9].

The difficulty interdependence creates is that an event in an interconnected structure can cause totally unknown effects on another entity inside the structure. Sometimes even cause-and-effect cannot clearly be determined [25].

Ambiguity

Ambiguity expresses uncertainty of meaning in which multiple interpretations are plausible. It can be defined as "too much information with less and less clarity on how to interpret and apply findings [32]." Ambiguity thereby covers the richness, accuracy and availability of information. Increased ambiguity is induced by a declining predictability of relevant aspects both inside and outside the organization [9].

Looking at the external perspective of an organization, ambiguity describes the unpredictable change of business environment and market conditions. Regarding the internal perspective of an organization, ambiguity leads to the existence of multiple, often conflicting situations, goals and processes. It has therefore been identified as an essential driver of organizational complexity.

Flux

The fourth dimension of the complexity framework is flux. It surrounds the other three dimensions and emphasizes their constant change and adaption to changing conditions [33]. Temporary solutions regarding interdependence, diversity and ambiguity for any specific industry or company can therefore be outdated from one day to another [34].

Flux can be found both inside and outside the organization. External influences can either be political or market-related changes, while internal influences come from change in strategy, change in individual behavior, change in processes or iterations during product development. Considering these possible roots of flux enables companies to allocate resources appropriately and manage complexity [9].

B. Drivers of organizational complexity growth

There are many reasons why complexity has been growing in many areas of modern businesses. One of the major influences and core challenges in organizations has proven to be globalization. Other influences of rising complexity in organizations have been found to be division of labor, the formation of cross-functional teams and the introduction of concurrent engineering.

Globalization

Globalization as a term for international integration regarding business, work, economics, culture, politics and natural resources has influenced the social sciences since the 1990s. Various definitions can be found stating that globalization is a process in which the world becomes "united" [35], intensifying "worldwide relations which link distant localities" [36] on different levels of society, for example in the realms of politics, economics and culture [9]. In the business environment globalization has led to international capital flows, expansion of trade, development of new markets, dissemination of knowledge and international sourcing [37].

Summing up all elements of globalization it becomes clearer that globalization is a multi-dimensional process with various, dynamic, cross-linked and non-linearly interacting elements [9]. It thereby coincides with many of complexity's key elements. It boosts complexity by the erosion of boundaries, higher mobility, heterarchy and higher dynamics in all areas of life.

Division of Labor and Specialization

Division of labor as *the* fundamental feature of a modern or developed economy has enabled gigantic increases in volume, variety of products and technical advancement [38]. The term is used to describe the division of complex production and development processes into a number of simpler tasks, each undertaken by an individual or group that has focused or specialized for a certain set of tasks.

Breaking labor down to specialized individuals or groups helps to take advantage of workers' differing skills and talents, allowing achievement of comparative advantage [39]. Dividing its labor into distinct tasks and coordinating these tasks defines the structure of an organization [40]. Adding structure by dividing labor into smaller and more specialized tasks, organizations tend to move to higher complexity [41].

Concurrent Engineering and Cross-functional Teams

The basic concept of concurrent engineering (CE) is to parallelize and overlap the different phases of design to reduce the time needed to develop a product. It originated from the issues sequential development phases exhibited: Long development times, quality problems due to lack of communication and a weak understanding of customer needs [42]. In order to overcome these issues concurrent engineering requires the simultaneous, interactive and inter-disciplinary involvement of product development, manufacturing and supporting departments like purchasing and field service [43]. This requires early involvement of all enterprise functions that contribute to a successful product [44]. CE therefore breaks down traditional functional and departmental barriers by integrating team members with different discipline backgrounds within the organization, often known as cross-functional teams.

To implement CE, changes in the organizational structure and processes are required, as tasks and departments become more interdependent with each other. In order to be successfully synchronized, the overlapping activities require a more vigorous communication, coordination and collaboration compared with past development concepts [44].

C. Interim Conclusion

The aspects of organizational complexity introduced thus far lead to the question of how organizational complexity can be measured in order to enhance awareness and to avoid excessively complex project organizations. Further, an objective measurement may allow more precise assessments of a development project's cost and time.

The following section will conduct a brief review and evaluation of existing measurements to examine whether an appropriate measure already exists.

III. RELATED WORK

As already emphasized in the introduction, there is an unmet need for being able to measure complexity. To give a short overview about existing measures, this chapter will briefly describe and evaluate the most common and appropriate measures to quantify different forms of complexity. To understand why the existing measures are not sufficient to measure organizational complexity, the necessary requirements are briefly laid out.

A. Requirements

In order to fully and comprehensively reach various goals, a scientific approach should meet some fundamental requirements. There are two main categories a scientific approach should comply with in order to measure organizational complexity: Methodological requirements and requirements that are derived from the area of application. Methodological requirements comprise features like a visible and systematical procedure, objectivity and the correctness of model. Requirements that result from the area of application are dedicated to aspects of complexity and organizations. Regarding the objective measurement of complexity, Eppinger defines five fundamental elements that complexity measurements for organizations, processes and products should address [45]:

- Number of decomposed elements (components, tasks or teams depending on assessed dimension)
- Number of interactions managed across the elements
- Uncertainty of the elements and their interfaces
- The patterns of the interactions across the elements (density, scatter, clustering, etc.)
- Alignment of the interaction patterns from one domain to another

Organizational complexity measurement should also address the previously-developed framework of organizational complexity, capturing the four dimensions diversity, interdependence, ambiguity and flux. The measurement should further include human factors such as sociality, behavior and cognition as these factors mainly differentiate organizations from non-living and non-human systems.

B. Current Approaches

Current approaches to characterizing organizational complexity investigated in this paper are widely spread across different research disciplines as organizational complexity represents an interface function between complexity and organizations. Moreover, many complexity areas are closely related to project organizations, e.g. projects, networks, etc. In order to provide a concise overview, the most promising approaches are investigated, which were chosen regarding the fulfilment of above-mentioned requirements.

The first approaches investigated aim at quantifying organizational complexity consistent with the topic of this paper. The investigation is then extended to project and network complexity as development projects represent a particular form of projects and organizations resemble networks of information transformation and social interaction. Finally, other promising measures besides organizational, project and network measurements are analyzed.

Organizational Complexity Measurements

System complexity measure by Malone & Wolfarth [10] is an organizational complexity measure based on McCabe's [46] cyclomatic complexity developed to assess the complexity of software code. Although the method fulfils most of the requirements, it is a very simple assessment and does not incorporate organizational characteristics like human behavior and cognition. It is therefore not sufficient to explain complexity emergence based on human interaction and the difficulties that derive from global development projects.

Organization Coordination Network Complexity Measure by Wang et al. [47] quantifies the complexity of organizational information transformation and organizational structure. In order to quantify complexity it combines scores for both aspects in a unified value. The measurement is based on entropy calculations and network theory. As organizations represent networks with structure and information processing and transformation, the measurement fulfils the basic requirements. Nevertheless it falls short on including human behavior and cognition characteristics and therefore is overly simplified and imprecise as an assessment tool.

Organizational complexity measure by Schwandt [9] is based on a broad collection of complexity factors in order to build an overall measurement framework. Although this framework is consolidated and broken down to the most influential factors through an empirical validation, this method only evaluates market-driven complexity and fails to address complexity that emerges from processes inside the organization. Furthermore, no procedural guidance apart from setting up the framework is given.

Project Complexity Measurements

The project complexity measure by Vidal et al. [12] is based on a very broad empirical study in order to put up a framework with the most influential factors regarding project complexity. The primary contribution through an empirical study is that the majority of factors they identified for their framework are organizational in nature. Although the derived framework has a wide variety of factors and can thereby capture different aspects of complexity, the mathematical model does not fulfil the required goals. It further only measures a relative score, which makes it difficult to estimate complexity in a single project.

Schlick et al. [4] developed a method to compute the complexity of new product development projects. The approach is based on entropy theory and the work transformation matrix. It quantifies product development complexity by taking into account stochastic elements caused by the project itself and the outside world. The assessment is based on a formula to quantify development project complexity. However, as it is designed for processes, it does not incorporate human characteristics and therefore cannot fulfil all set-up requirements.

Network Complexity Measurements

Structural complexity in global production networks by Schuh et al. [48] is a complexity measure for quantitative assessment and optimization of global production networks. It is divided into two steps: quantitative assessment and visual optimization. The quantitative assessment captures how close different production sites are working together, at what cost and how difficult coordination inside and between the sites is going to play out. The fundamental model could be applied to product development organizations, but organizational complexity features based on human behavior are nevertheless missing.

Sinha's [16] measurement model for structural complexity was developed to quantify the complexity of a product consisting of various components. As it is a network based complexity measure taking into account the complexity of components as well as the complexity of interfaces, it could basically work well for organizations. However, due to its focus on product complexity it lacks important organizational characteristics and is therefore not applicable without modifications and the incorporation of organizational factors.

Other Complexity Measurements

The generalized complexity index by Jacobs [26] was primarily developed to calculate the complexity of products. Nevertheless, the author emphasizes that the generalized complexity index can be used in many different fields, for example in product portfolios and organizations. The method is based on the three complexity dimensions: interconnectedness, diversity and multiplicity. It offers a calculation method for each of these dimensions. Although the complexity dimensions are partially met, the method neither includes organizational features nor meets all required measurement characteristics.

C. Interim Conclusion

Summarizing the evaluation results one finds that no approach currently meets all the elaborated requirements. Methods like Sinha's structural complexity measure for products or the Schuh et al. structural complexity measure for global production networks fulfil many of the required aspects but lack organizational characteristics. They therefore do not measure the intended aspects or have to be adapted (if possible) and modified. The organizational complexity measure by Schwandt and project complexity measure by Vidal et al. suggest a wide range of factors that influence organizational complexity. Nevertheless, they do not supply a detailed objective measurement procedure.

Taken together, this results in the need for the development of a measurement of organizational complexity in product development projects which integrates organizational complexity factors and an adequate metric fulfilling all previously defined requirements.

Research questions

This leads to the following research questions this paper will address:

- *What are the driving factors of organizational complexity?*
- *How can these factors objectively be measured in a feasible manner?*

IV. APPROACH

The goal is to develop a measuring method that enables the quantification of the amount of complexity inside product development project organizations. Being aware of complexity and adjusting it to the specific needs may become a key competence in future development projects to fulfil customer demands at low cost and short development cycles. Only by the awareness and understanding of organizational complexity will companies be able to effectively avoid, reduce and handle it. Further, the assessment enables quantitative approaches that estimate cost and benefit of organizational complexity. One is thus supported to take complexity based decisions.

The following approach is split in four parts to guarantee a better understanding of the underlying concept and the developed mathematical model and procedure. The first step is to briefly define the area to which the approach is meant to be applied, followed by the identification and clustering of constituent factors of organizational complexity in a second step. A third step develops a mathematical model and systematic procedure. The fourth and last step helps to interpret the acquired results by visualization. It further gives some guidance how to manage organizational complexity.

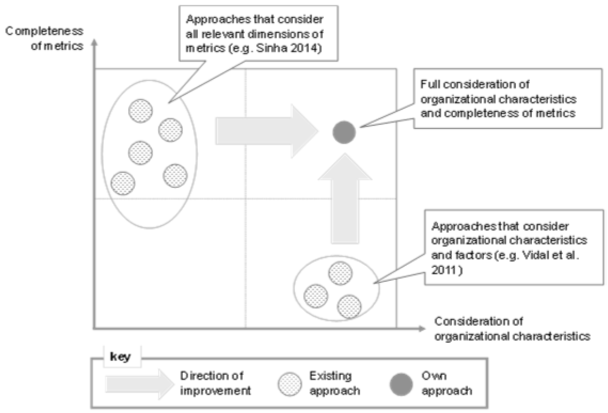

Figure 5: Deficits in current approaches and target solution

Figure 5 shows the key aspects a newly developed method needs to focus on to enhance the accuracy of measurement and simultaneously incorporate all relevant influence factors.

A. Demarcation

It is important to determine the application area to ensure reliable results. Referring to the introduction chapter, the aim of this method is to assess organizational complexity in product development projects. In detail this implies:

- The object of observation is organizational complexity, derived from integrating organizations and complexity
- The context of analysis is product development projects

Further, this paper only concentrates on complexity which is rooted inside organizations (internal complexity). All organizational complexity that is caused by external influences will not be considered as they will be considered beyond the control of project managers. Also, it is important to note that organizational complexity due to its link to human characteristics is time-dependent and changes over time. The same factor will most likely not have the same expression at the end of the project as it had at the very beginning (e.g. social interactions develop over time). Because of that, the method views an organization as a "system in a flux with temporal stability." [49] The assessment therefore has to continuously be repeated.

Project organizations are differentiated from "regular" organizations as they are usually temporary in their structure and processes. Moreover, project organizations are often multi-organization concepts where the tasks and resources are spread and shared across contributing partners. This view is adapted in this paper and organizations are viewed as multi-organizational entities.

B. Factor Identification and Clustering

Identifying the relevant complexity driving factors is one of the most important tasks when developing a measurement method. In order to achieve significant contribution to the current scientific knowledge, the factors have to fulfil 3 requirements. First they have to fulfil the criteria for multi factor decision methods, which should be *operational and meaningful, non-redundant, few in number and able to discriminate between different levels of complexity* [12]. Secondly they have to align to the previous demarked research area and match with the four organizational complexity dimensions. Third the factors have to be scientifically evaluated and demonstrated to contribute to organizational complexity.

During the research, 44 factors were identified in literature that fulfilled the strict literature and complexity criteria. Most popular sources of factor identification were organizational complexity frameworks, project complexity frameworks, process complexity and network complexity research. In order to meet multi factor requirements, these 50 factors had to be stripped down to a more tractable number. When examining the list of factors, it became clear that many factors are in fact very similar or measure the same/similar aspect of complexity and can thus be consolidated into clusters. A method similar to hierarchical clustering analysis was determined to be the most appropriate.

In order to generate the required data to perform a cluster analysis, cause and effect relationships between the factors were analyzed. The expression of each factor was therefore varied in a narrow range and the impact on the other factors was recorded. Factors influencing each other indicates that they measure similar aspects of organizational complexity and are thus in some way interdependent. For the success of a measurement, however, independence and non-redundancy are essential requirements.

In order to constitute non-redundant and independent clusters, the web of cause and effect relationships was investigated. A deeper analysis found that the factors are concentrated within eight major cause and effect chains that have basically no influence on each other and are thus independent. The eight independent cause and effect chains constitute the eight independent clusters described below. In order to assign each of the clusters with a name, the clusters were examined according to their main contribution to organizational complexity. Factors at the end of each cause and effect chain consolidate all the upstream factors and thus establish the name and measurement of each cluster. Results of the analysis are the clusters described below. They resemble different aspects of organizations and organizational complexity (also see Figure 6 for an overview):

- Interdependence
- Management hierarchy
- Operating standard procedure
- Location
- Information systems alignment
- Objective (incentive) alignment
- Personality
- Culture

The developed clusters are few in number and non-redundant. Each of these factors can have various expressions which helps to distinguish between different levels of complexity. A most simplistic way to distinguish between different complexity levels can be achieved by assigning each factor with a scale from 1 (low level of complexity) to 5 (high level of complexity).

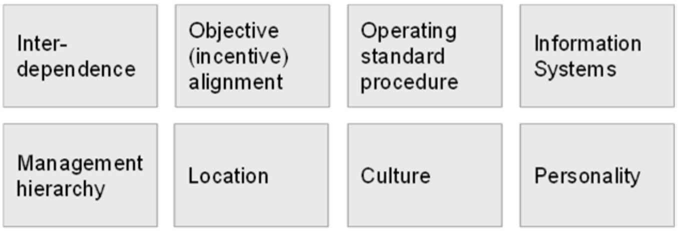

Figure 6: 8 clusters of organizational complexity

Factor identification by itself, however, does not make an objective measurement yet. The next step is to develop a mathematical model, which helps to (i) distinguish between different levels of complexity and (ii) support the generation of a global complexity score for the overall project organization.

C. Mathematical Model and Application Procedure

Goal of a mathematical model and a given application procedure is to objectively measure the identified clusters. To reach that goal, the mathematical model will be developed in a first step. To clarify the application procedure and validate the measurement in a second step, an application example will be given in chapter V.

Sinha's previously described measurement model for complexity assessment of cyber-physical systems was found to be a very good foundation for the developed model. It fulfils all mathematical requirements although it was initially developed for product complexity. It is defined as [50]:

$$C = C_1 + C_2 * C_3 \quad (1)$$

C_1 in this case represents the complexity of the product components, while C_2 accounts for the interface complexities and C_3 for the arrangements of interfaces of a physical product.

In order to apply to organizations, some adaption had to be undertaken. Organizations can be represented by three different levels [51], namely, (i) the individual level, (ii) the group level and (iii) the overall organizational level. Organizational goals from the top level are broken down to the lower levels in order to achieve development progress (see Figure 7).

Interface complexities C_2 and the arrangement of interfaces C_3 can be calculated on both the group level and the organizational level. Due to no interfaces on the individual level, no interface or interface arrangement can be calculated there. Component complexities as represented by C_1 in Sinha's model are nowhere to be found in organizations as individuals are assumed not to feature an inherent complexity.

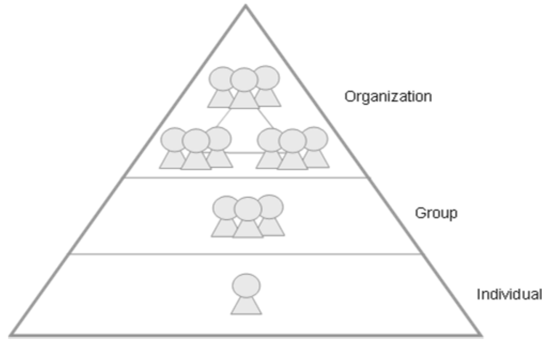

Figure 7: Three organizational levels: Individual, group and organization

In order to capture the overall organizational complexity, one has calculate complexity inside a group (intra-group complexity – group level) and between the groups (inter-group complexity – organization level). The new mathematical model based on Sinha [50], is expressed in equation 2:

$$C = C_{2G} * C_{3G} + C_{2O} * C_{3O} \quad (2)$$

The mathematical model consists of two elementary terms in order to quantify organizational complexity C. The first term $C_{2G} * C_{3G}$ quantifies the complexity at the group level, whereas the second term $C_{2O} * C_{3O}$ assesses the complexity at the organizational level between groups (see Figure 8 for a detailed illustration).

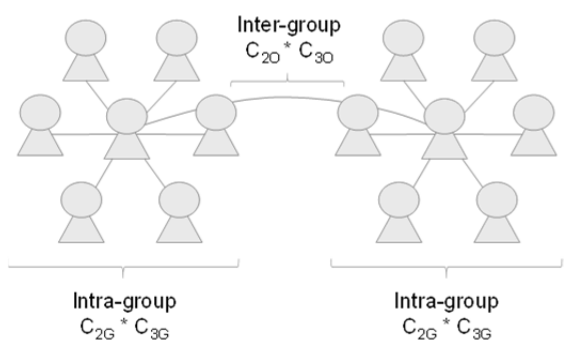

Figure 8: Intra-group and inter-group complexity

The idea behind the model is that an organization can be regarded as a social network [14][52] that processes information [53][54][55][42] and communicates in order to achieve a specific set of tasks. In order to calculate the complexity of those information processing structures we measure the complexity on two different levels: The complexity inside each group as the smallest formation of employees and the complexity between these groups.

On both levels the complexity is calculated equally. Each elementary term consists of two components: (i) number and complexity of each pair-wise interaction which is calculated by C_{2G} (and C_{2O}) and (ii) effect of architecture or the arrangement of the interactions (C_{3G} and C_{3O}). The effect of architecture is important to incorporate as the same number of interactions can exhibit different levels of complexity. A more centralized system generally has a lower complexity than a distributed one, although both share the same amount of interactions [50][56]. The architecture of a system (group or entire development organization) is represented by the associated DSM (see section "Architecture complexity C_{3G} and C_{3O}" for detail).

Retrieving the previously identified clusters, one finds that there are basically three cluster types: One cluster determining the strength and importance of each interface (interdependence), one cluster determining the arrangement of interfaces (management hierarchy) and clusters determining the specific characteristics of each interface or of the connected elements (remaining ones). Strength and characteristic clusters will therefore be used to describe the interfaces (C_2), whereas the management hierarchy will be represented by C_3. C_3 determines the network complexity and therefore the complexity to manage and coordinate. The calculation of C_2 and C_3 will be explained below.

Interface complexity factor C_{2G} and C_{2O}

Interfaces are part of a system and enable communication across several parts. They are therefore often equated with interaction. This paper will equally use both expressions.

Factor C_{2G} (and C_{2O}) measure the interaction complexity. In order to calculate each interaction complexity, we utilize strength and characteristic clusters which both characterize the complexity of interface and interaction.

Each interaction can be modeled as a function of two parts (see equation 3). The first term s_{ij} measures the strength of interaction in order to be able to generate a relevance score for each interaction. More relevant (stronger) interactions have a higher contribution to organizational complexity than less relevant interactions. To calculate the strength of interaction, we utilize the previously identified cluster *interdependence*. The second term c_{ij} expresses the complexity of each interaction. It is a function of the six interface characteristic clusters.

$$C_2 = f(s_{ij}, c_{ij}) \quad (3)$$

s_{ij} is assessed by evaluating the strength of each pair-wise interaction. How can we estimate the interaction strength inside a project organization? Although there is no direct way to estimate it, there is a very precise indirect way to do that by indirectly deducing relationships from other levels of abstraction [57]. Individual development projects have three levels of abstraction. The highest level of abstraction is the product in development (see Figure 9). The product translates into different tasks that have to be accomplished in order to achieve progress in the development. The tasks again can be linked to organizational units (individuals or groups) carrying out these tasks.

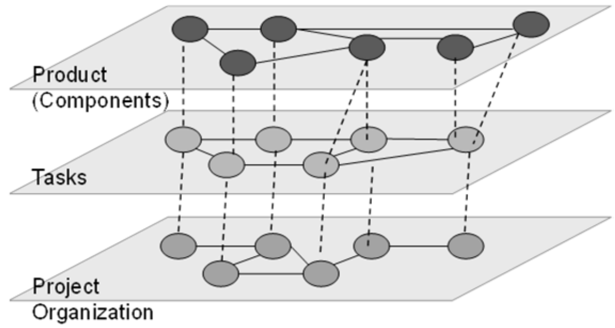

Figure 9: Levels of abstraction in product development

As there is no direct measure for interaction strength of organizational units, we utilize the task interdependence on the above abstraction level in Figure 9. Task interdependence is a measurable value [58][59]. We then link the organizational entities to the interdependent task and thereby get a value for the interdependence and interaction strength between organizational entities (see Figure 10). The use of multiple domain matrices (MDM) helps to illustrate and transform the interdependence between tasks to the lower abstraction level of organizational units [57]. By doing so, the interdependence on the lower abstraction level is assessed.

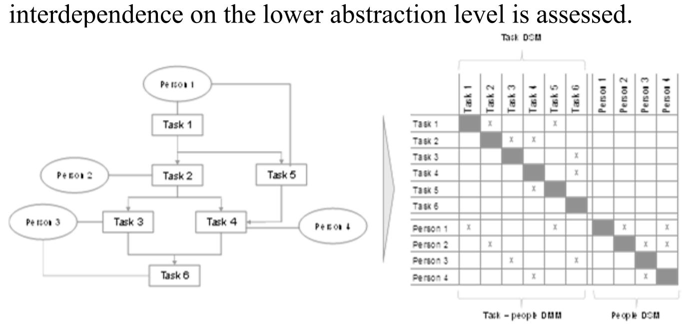

Figure 10: Task - entity mapping

In order to estimate the interdependence of tasks, we propose the use of *fraction of task that is dependent on input* and the *level of overlap* (task percentage where data is exchanged). Both elements are rated on a 0 to 5 scale with 0 equaling no information dependence and data exchange and 5 expressing very high information dependence and data exchange.

c_{ij} express the complexity score of each interaction. We use the six remaining clusters to evaluate the interaction complexity of each pair-wise interaction. We thereby get the interaction complexity vector $\overrightarrow{c_{ij}}$.

$\overrightarrow{c_{ij}}$ has a slight different representation on group and organizational level (see Figure 11). On group level one can easily assess personality match between two entities, for example by comparing their Myers-Briggs type indicator (MBTI). On organizational level however, as groups are often very heterogeneous in their personality, that metric cannot be calculated. Both vectors are represented in equation 4.

Strongly differing cluster expressions of interacting organizational units show a high complexity (score 5) whereas close values indicate low complexity (score 1). For example, strongly different objectives of interacting entities suggest a high complexity rating, whereas an interaction within or between co-located groups indicates a low location complexity.

$$\overrightarrow{c_{ijG}} = \begin{pmatrix} Location \\ Operating\ standard\ procedure \\ Objective\ alignment \\ Information\ systems \\ Culture \\ Personality \end{pmatrix} \qquad \overrightarrow{c_{ijO}} = \begin{pmatrix} Location \\ Operating\ standard\ procedure \\ Objective\ alignment \\ Information\ systems \\ Culture \end{pmatrix}$$

Figure 11: Interface characteristic vector $\overrightarrow{\boldsymbol{c_{ijG}}}$ and $\overrightarrow{\boldsymbol{c_{ijO}}}$

As not all clusters inside the vector are of the same importance to the contribution of complexity emergence, a weighting mechanism needs to be included. In the long run, this weighting should be based on the contribution of each cluster to complexity cost. In the short run, as no data on complexity cost are available, a simple AHP weighting is proposed. Project managers with insight into product development should assess the clusters and rate them in a pair-wise comparison against the company's ability to manage each cluster.

Overall C_2 can be calculated as the product of strength s_{ij} (relevance), weighting vector $\overrightarrow{w_{ij}}$ and interface complexity vector $\overrightarrow{c_{ij}}$ of each pair-wise interaction.

$$C_2 = \sum_{i=1}^{n}\sum_{j=1}^{n} s_{ij} * (\overrightarrow{w_{ij}} * \overrightarrow{c_{ij}}) \tag{4}$$

Architecture complexity C_{3G} and C_{3O}

Factor C_{3G} (and C_{3O}) represent the "topological complexity" and measure the complexity of the overall interaction structure. It is defined as the matrix energy or graph energy of the adjacency matrix. Topological complexity originates from the interaction between elements and depends on the nature of such a connectivity structure. The adjacency matrix $A \in M_{nxn}$ of a network is defined as follows [56]:

$$A_{ij} = \begin{cases} 1\ \forall\ [(i,j)|(i \neq j) \text{ and } (i,j) \in \Lambda \\ 0 \text{ otherwise} \end{cases} \tag{5}$$

Where A represents the set of connected nodes. The diagonal elements of A are zero. Notionally, this quantity encapsulates the "intricateness" of structural dependency among components. The associated matrix energy of the network is defined as the sum of singular values of the adjacency matrix:

$$A(E) = \sum_{i=1}^{n} \sigma_i \text{, where } \sigma_i \text{ represents i}^{\text{th}} \text{ singular value} \tag{6}$$

Factor C_3 is equated with A(E)/n, where A(E) represents matrix energy and n accounts for the number of nodes. Matrix A has already been constructed when the interactions between organizational entities were derived from the tasks interdependencies. C_3 can therefore be estimated.

D. Visualization and Management

Complexity management represents the final and logical step in order to derive benefits from the complexity assessment results. To do so, two visualizations are proposed which help to better interpret the data provided by the mathematical model.

Visualization is a process to represent non-visual information in visual form. The spectrum of visualizations ranges from tables to simple graphical illustrations up to three-dimensional representations and real images. Pictorial representations serve to uncover complex structures, trends and relationships for the viewer. The aim to communicate the information in a comprehensible way and to facilitate the analysis, understanding and communication of models, concepts and data from different scientific disciplines [60].

The human brain is not designed to interpret data by the use of tables. It more likely recognizes patterns in the form of graphic-visual figures and thereby processes and interprets large amounts of data [61]. Thus an important requirement for visualizations is that it be not too complex so that third parties can identify and understand problems [62].

Visualization of complexity in product development projects has three main goals: Complexity avoidance, complexity reduction and complexity mastery (see Figure 12). Complexity avoidance has – compared to the other two strategies – a bigger effect with a longer duration as it prevents complexity from emerging throughout the whole product lifecycle [63].

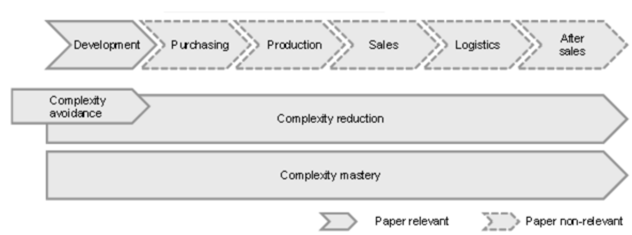

Figure 12: Complexity strategies [63]

Complexity avoidance as the first strategy requires complexity awareness. The mathematical model enables the measurement of complexity on different levels of organizations and thus strengthens awareness. Complexity reduction as the second strategy describes how and where to effectively and efficiently reduce excessive complexity. Complexity mastery as the third strategy describes how to handle and cope with non-avoidable complexity.

For all strategies, we propose two different visualization techniques for better complexity identification. The first one visualizes different project alternatives in order to be able to pick the alternative with the lowest complexity score (complexity avoidance). The second technique is called "complexity heat map" (complexity avoidance, reduction and mastery). Comparable to other heat maps, it illustrates complexity levels inside the project organization with different colors (white for no interface, yellow for low complexity and red for high complexity). Both techniques will be illustrated in the next section (see Figure 15 and Figure 16 for examples).

By applying the complexity heat map, complexity hotspots inside the project organization become more evident, further supporting efforts to lower the complexity at those spots or to more effectively manage it. Responses to complexity could include standardization of operating procedures, co-location of employees or workshops to help them deal with high levels of complexity. The employees could for example be trained to work with non-standardized processes, unknown information sources, different objectives or high process interdependence.

The complexity heat map is established as follows: The diagonal displays each group's internal complexity which can be calculated by the term C_{2G}*C_{3G} for each group. The numbers off-diagonal display the pair-wise complexity between two groups (C_2). Fields with high numbers of complexity are marked in red, while fields with low numbers are marked in green. By this visualization, the observer gets a picture about complexity hotspots inside the project organization in a very short time. Further, this depiction is easy to understand and requires very little explanation among the users.

In addition, a general management approach similar to Figure 13 should be put in place. A too high organizational complexity (compared to the available capacity) should lead to an organizational reconfiguration and redesign. If neither redesign nor reconfiguration can help to push organizational complexity below the capacity, the project constraints (e.g. customer requirements) need to be modified.

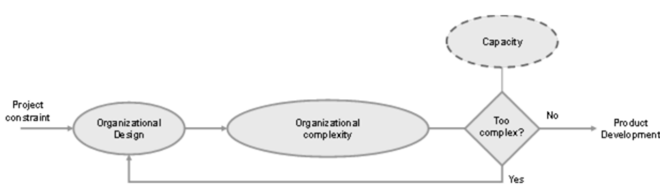

Figure 13: Control circuit for the management of organizational complexity

Although there is no known measurement for the complexity capacity yet, a good orientation is to compare the project in question to complexity scores of past projects. If a new development project greatly exceeds the organizational complexity that has been handled in past projects, the organization might not be able to manage and handle such high levels.

V. APPLICATION EXAMPLE

In order for a better understanding and validation of the prior described measurement method, an application example with 3 different scenarios is given. The case described is a fictional example but is closely related to a real world, yet confidential case study.

The fictional development case is scheduled to comprise 18 tasks, starting with developing a concept and terminating with the development of a final manufacturing scheme. The expected amount of work effort totals 187 hours.

The company usually develops products internally without drawing on external experts or suppliers. Due to cost pressure and shrinking margins, the company contemplates out-sourcing certain tasks of the development process. In particular, tasks that do not represent the company's core competences are considered for outsourcing.

The company identifies task 4 *perform materials analysis,* task 6 *perform feasibility analysis* and task 12 *perform load analysis* to be candidates for outsourcing. Three case scenarios are thereby: Scenario A as the base scenario performs all tasks internally in Germany. Scenario B proposes to outsource to an external contractor that the company has worked with in the past. This contractor is located in France. Scenario C, where the company anticipates the highest cost savings, is located in China. The company has never worked with that contractor before.

In this example, the task interdependencies have already been assessed by the company. The linkage to organizational units und the deduction of interdependencies is simple as each task is performed by one specialized individual. Factor s_{ij}, the strength of each pair-wise interaction, is therefore determined.

To assess the complexity of factor c_{ij} we investigated each interaction and matched it with the related complexity scores.

In the base scenario A, all employees are located at the same plant with a high workweek overlap (location complexity 1), are of the same origin (culture complexity 1) and have aligned roles and processes (operating standard procedure 1). Objectives are aligned due to the same company and a shared project goal (objective alignment 1), information systems are mostly aligned (information systems 2), whereas personality score varies between 1 and 5 depending on the interface.

Scenario B, outsourcing of tasks to a contractor in France has the following impacts: The location complexity rises due to a longer distance but a stable workweek overlap (location complexity 3), cultural complexity rises due to major cultural differences in 2 dimensions regarding to Hofstede [64] (cultural complexity 3), roles and processes are partly standardized due to past projects (operating standard procedure 3), objectives are partly aligned (global project goal, local company goals), the information systems only overlap around 40% (information systems 4), whereas personality score varies between 1 and 5 depending on the interface.

Scenario C, working with a contractor in China to perform the development has the following impacts: Location complexity rises to the highest level due to far distance and basically no workweek overlap (location complexity 5), cultural complexity also sharply rises due to a high cultural distance with major cultural differences in 4 cultural dimensions (culture complexity 5), roles and processes are not standardized due to no previous project experience (operating standard procedure 5), objectives are not aligned as the project has no priority for the Chinese company (objective alignment 5), information systems only overlap around 50% (information systems 4) and personality score varies between 1 and 5 depending on the interface.

Please note that scenarios B and C only apply to interfaces connecting with the external contractors. All other interfaces remain as described in the base scenario.

Once all the data is established, the clusters need to be weighted. By using pairwise comparisons, a fictional weighting was established, based on industrial experience of the authors:

Operating standard procedure	Location	Information systems alignment	Incentive alignment	Culture	Personality
0,3	0,2	0,2	0,2	0,05	0,05

Figure 14: Cluster weighting

Utilizing equation 2 and cancelling out the organizational level as this small development project is accomplished only on group level (each worker is assigned with one task) we get the following results (see Figure 15): Scenario A has an organizational complexity of about 460, due to an aligned development procedure and experience with collaboration. Scenario B has a significantly higher complexity, due to spatially divided work, not fully-aligned processes, systems and objectives. Scenario C has an even higher complexity due to unexperienced collaboration, cultural differences and mostly unaligned systems and processes.

The impact of outsourcing is significant due to the high interdependence of the chosen tasks. Outsourcing around 20% of the product development tasks in this case causes a complexity increase of around 40% to 75%, depending on the scenario.

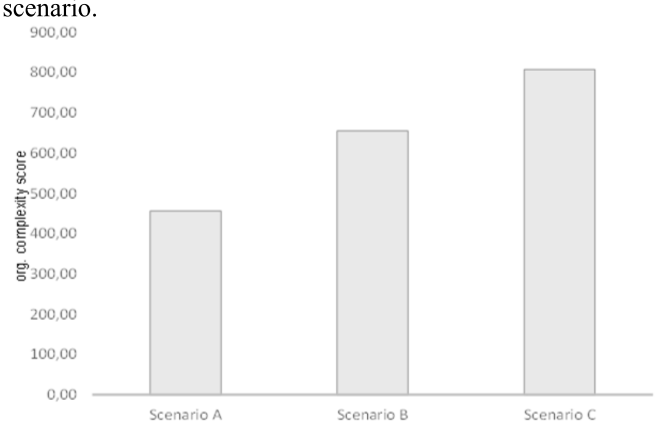

Figure 15: Organizational complexity in scenario A, B and C

Outsourcing tasks that are not as severely incorporated into the development process cause a much smaller increase in organizational complexity. Outsourcing tasks 8, 14 and 15 under the same conditions, for example, only increases organizational complexity by around 30% to 55% (not illustrated in this paper). Examining organizational interdependencies can therefore be a first step when evaluating which tasks to outsource.

Analyzing the impact on complexity hotspots (see Figure 16, Figure 17 and Figure 18) one will find severe changes that are to be expected by outsourcing. Scenario A basically has an equal distribution of complexity inside the organization. Differences in complexity arise from different levels of interdependencies, slightly varying locations and personality scores. Complexity heat-map B illustrates a significant change. Hotspots are concentrated along the interfaces between the base company and the external contractor. Heat map C is similar with an even stronger emergence of organizational complexity along the external interfaces.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		1,66	0,00	1,45	1,76	0,91	0,00	0,00	0,00	1,73	1,61	0,00	1,26	0,00	1,17	0,00	0,00	0,00
2	1,41		0,00	0,00	2,98	2,41	0,00	0,00	0,00	0,00	1,62	3,13	2,84	0,00	0,00	0,00	2,65	0,00
3	3,62	0,00		0,00	0,00	0,00	6,50	0,00	4,05	0,00	2,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	0,49	4,19	0,00		3,35	0,83	0,00	0,00	0,00	0,00	1,82	3,51	0,98	0,00	0,00	0,00	0,00	0,00
5	0,58	0,05	0,00	3,26		2,32	0,00	0,00	0,00	0,00	2,09	3,12	2,83	0,00	0,00	0,00	0,00	0,00
6	0,80	0,77	0,00	2,18	1,92		0,00	0,00	0,00	2,60	0,98	2,09	1,89	0,00	0,00	0,00	0,00	0,00
7	2,75	0,04	4,28	0,00	0,00	0,00		0,00	4,40	0,00	2,89	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8	0,00	0,00	0,00	0,93	0,03	0,00	3,32		0,00	0,00	1,40	2,89	0,00	0,00	0,00	1,99	0,00	2,29
9	2,33	0,06	3,73	0,00	0,00	0,00	6,15	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,05	0,00	3,74	3,41	0,85	0,00	0,00	0,00		1,85	3,58	1,00	0,00	0,00	0,00	0,00	0,00
11	2,24	0,03	0,00	0,71	0,84	0,48	0,00	0,00	0,00	0,85		2,21	2,00	0,00	1,99	0,00	1,70	0,00
12	0,02	0,06	0,00	4,06	3,71	0,92	0,00	0,00	0,00	1,50	2,01		1,09	0,00	0,00	0,00	0,00	0,00
13	0,02	0,06	0,00	1,39	0,05	1,02	0,00	0,00	0,00	1,66	2,22	4,30		0,00	0,00	0,00	0,00	0,00
14	0,00	0,02	0,00	0,43	0,02	0,00	0,00	0,68	0,03	0,51	1,57	0,00	1,21		0,00	2,08	0,00	2,39
15	0,90	2,79	0,00	0,03	0,03	0,05	0,00	0,00	0,00	0,90	1,10	0,03	2,12	0,00		0,00	4,46	0,00
16	0,00	0,00	1,61	0,00	0,00	0,00	0,00	2,56	2,66	0,00	0,00	0,03	0,00	1,97	2,64		0,00	4,68
17	0,71	2,21	0,00	1,94	1,71	1,94	0,00	0,00	0,00	1,40	0,87	1,85	1,68	0,00	4,14	0,00		0,00
18	0,00	0,00	2,04	0,00	0,00	0,00	0,00	1,96	0,07	0,00	0,00	0,04	0,00	2,50	0,00	5,15	2,86	

Figure 16: Scenario A complexity heat map

Although the given example is quite basic compared with bigger development projects where more than just two companies collaborate within the development process, the heat-maps give a good indication of which interfaces contribute to high complexity. If these interfaces are effectively modified, one can significantly reduce overall complexity.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		1,66	0,00	3,57	1,76	2,23	0,00	0,00	0,00	1,73	1,61	0,00	1,26	0,00	1,17	0,00	0,00	0,00
2	1,41		0,00	0,00	2,98	5,93	0,00	0,00	0,00	0,00	1,62	7,70	2,84	0,00	0,00	0,00	2,65	0,00
3	3,62	0,00		0,00	0,00	0,00	6,50	0,00	4,05	0,00	2,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	1,20	10,31	0,00		8,24	0,83	0,00	0,00	0,00	0,00	4,47	3,51	2,42	0,00	0,00	0,00	0,00	0,00
5	0,58	0,05	0,00	8,02		5,70	0,00	0,00	0,00	0,00	2,09	7,68	2,83	0,00	0,00	0,00	0,00	0,00
6	1,96	1,89	0,00	2,18	4,72		0,00	0,00	0,00	6,40	2,41	2,09	4,66	0,00	0,00	0,00	0,00	0,00
7	2,75	0,04	4,28	0,00	0,00	0,00		0,00	4,40	0,00	2,89	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8	0,00	0,00	0,00	2,30	0,03	0,00	3,32		0,00	0,00	1,40	7,12	0,00	0,00	0,00	1,99	0,00	2,29
9	2,33	0,06	3,73	0,00	0,00	0,00	6,15	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,05	0,00	9,20	3,41	2,09	0,00	0,00	0,00		1,85	8,81	1,00	0,00	0,00	0,00	0,00	0,00
11	2,24	0,03	0,00	1,75	0,84	1,17	0,00	0,00	0,00	0,85		5,44	2,00	0,00	1,99	0,00	1,70	0,00
12	0,05	0,14	0,00	5,31	9,13	1,21	0,00	0,00	0,00	3,68	4,95		2,68	0,00	0,00	0,00	0,00	0,00
13	0,02	0,06	0,00	3,41	0,05	2,51	0,00	0,00	0,00	1,66	2,22	10,58		0,00	0,00	0,00	0,00	0,00
14	0,00	0,02	0,00	1,06	0,02	0,00	0,00	0,68	0,03	0,51	1,57	0,00	1,21		0,00	2,08	0,00	2,39
15	0,90	2,79	0,00	0,07	0,03	0,12	0,00	0,00	0,00	0,90	1,10	0,07	2,12	0,00		0,00	4,46	0,00
16	0,00	0,00	1,61	0,00	0,00	0,00	0,00	2,56	2,66	0,00	0,00	0,08	0,00	1,97	2,64		0,00	4,68
17	0,71	2,21	0,00	4,77	1,71	4,78	0,00	0,00	0,00	1,40	0,87	4,56	1,68	0,00	4,14	0,00		0,00
18	0,00	0,00	2,04	0,00	0,00	0,00	0,00	1,96	0,07	0,00	0,00	0,11	0,00	2,50	0,00	5,15	2,86	

Figure 17: Scenario B complexity heat map

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		1,66	0,00	5,25	1,76	3,28	0,00	0,00	0,00	1,73	1,61	0,00	1,26	0,00	1,17	0,00	0,00	0,00
2	1,41		0,00	0,00	2,98	8,71	0,00	0,00	0,00	0,00	1,62	11,31	2,84	0,00	0,00	0,00	2,65	0,00
3	3,62	0,00		0,00	0,00	0,00	6,50	0,00	4,05	0,00	2,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	1,77	15,14	0,00		12,10	0,83	0,00	0,00	0,00	0,00	6,56	3,51	3,55	0,00	0,00	0,00	0,00	0,00
5	0,58	0,05	0,00	11,78		8,37	0,00	0,00	0,00	0,00	2,09	11,28	2,83	0,00	0,00	0,00	0,00	0,00
6	2,88	2,78	0,00	2,18	6,93		0,00	0,00	0,00	9,40	3,54	2,09	6,84	0,00	0,00	0,00	0,00	0,00
7	2,75	0,04	4,28	0,00	0,00	0,00		0,00	4,40	0,00	2,89	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8	0,00	0,00	0,00	3,37	0,03	0,00	3,32		0,00	0,00	1,40	10,46	0,00	0,00	0,00	1,99	0,00	2,29
9	2,33	0,06	3,73	0,00	0,00	0,00	6,15	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	0,00	0,05	0,00	13,51	3,41	3,07	0,00	0,00	0,00		1,85	12,93	1,00	0,00	0,00	0,00	0,00	0,00
11	2,24	0,03	0,00	2,57	0,84	1,72	0,00	0,00	0,00	0,85		7,99	2,00	0,00	1,99	0,00	1,70	0,00
12	0,08	0,21	0,00	4,06	13,41	1,78	0,00	0,00	0,00	5,41	7,27		3,94	0,00	0,00	0,00	0,00	0,00
13	0,02	0,06	0,00	5,01	0,05	3,69	0,00	0,00	0,00	1,66	2,22	15,54		0,00	0,00	0,00	0,00	0,00
14	0,00	0,02	0,00	1,56	0,02	0,00	0,00	0,68	0,03	0,51	1,57	0,00	1,21		0,00	2,08	0,00	2,39
15	0,90	2,79	0,00	0,11	0,03	0,18	0,00	0,00	0,00	0,90	1,10	0,10	2,12	0,00		0,00	4,46	0,00
16	0,00	0,00	1,61	0,00	0,00	0,00	0,00	2,56	2,66	0,00	0,00	0,12	0,00	1,97	2,64		0,00	4,68
17	0,71	2,21	0,00	7,00	1,71	7,02	0,00	0,00	0,00	1,40	0,87	6,70	1,68	0,00	4,14	0,00		0,00
18	0,00	0,00	2,04	0,00	0,00	0,00	0,00	1,96	0,07	0,00	0,00	0,16	0,00	2,50	0,00	5,15	2,86	

Figure 18: Scenario C complexity heat map

VI. CONCLUSION AND OUTLOOK

This paper's objective is to propose a method for measuring organizational complexity, based on the previously-—identified call for action from a product development practice and research point of view.

For this purpose, in a first step factors driving organizational complexity enhancing the awareness and understanding of its emergence were identified. A broad literature analysis was conducted which revealed 44 factors responsible for the emergence of organizational complexity. In order to integrate these factors into a mathematical model in a next step, non-redundancy of the factors had to be ensured. For this purpose, a clustering mechanism based on the factor dependencies revealed eight independent clusters. These clusters illustrate which organizational aspects have major contributions to the emergence of organizational complexity. Considering these aspects during organizational design and configuration can already prevent organizations from becoming overly complex.

In a second step a measurement for organizational complexity was developed to discriminate between different levels of complexity. For this purpose, a mathematical model was developed. Sinha's model for measuring complexity of cyber-physical systems was found to be suitable and adaptable for organizations. Establishing the mathematical model enables calculation of organizational complexity on different levels of project organizations – intra-group level and inter-group level.

The outcome of these two steps helps in various aspects of complexity management: Complexity awareness by knowing which factors drive organizational complexity and complexity assessment by enabling measurement of the amount of complexity present in an organizational environment.

To enable drawing conclusions from the analysis in a last step, two main strategies for handling complexity in product development were given: Complexity avoidance and complexity mastery. Complexity avoidance pursues the goal of identifying complexity before it emerges by creating increased awareness. Awareness helps to proactively tackle complexity spots inside the project organization. Complexity mastery has the goal of supporting employees in coping with complexity. That might be achieved through special training.

For these two strategies two visualization tools were proposed: Visualization of project alternatives showing the complexity of each alternative enables selection of the project configuration with the lowest complexity or best complexity-benefit ratio. The second visualization technique is to illustrate complexity within a complexity heat map. The heat map can either be used to visualize intra-group complexity or inter-group complexity. By using this illustration, the user gets a very quick overview about complexity hotspots inside the organization. That hopefully can support better identification and management of high levels of complexity.

As a last step the newly-developed method was evaluated using a case example which showed notable complexity differences in three different scenarios with various organizational configurations. By that, we were able to visualize the effects of outsourcing of product development tasks to external contractors.

Comparing the results with the example of the Boeing 787 where Boeing outsourced around 70% of the development process to external suppliers and contractors (compared with a level of around 35-50% on previous projects and a significantly higher level of overseas outsourcing [6]), the fictional example provided in this paper provides some insights into why the 787 development might have experienced so many issues.

Despite this, outsourcing and emerging complexity are not a bad thing per definition, as long as the knowledge of possible side effects and the ability to handle complexity are present. If well-planned, aligned and executed, outsourcing could basically express the same amount of organizational complexity.

Further research should focus on the establishment of valid scales that go beyond the basic scales used in this approach. If the scales are evaluated and demonstrated to be reliable and valid, a subsequent step can examine a possible link between organizational complexity and costs. If a relationship between cost and organizational complexity can be demonstrated, this approach could support a decision tool for the design of project organizations for product development.

Moreover, in order to redesign projects that exceed the complexity capability of organizations, a measurement for complexity capacity should be developed. It can be either based on past project experiences or the individual capability to handle complexity.

ACKNOWLEDGMENT

The authors thank the German Research Foundation (DFG) for the support in the context of the project "Complexity evaluation of development projects" (SCHU 1495/87-1).

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