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Simulation-based Value Analysis of Organizational Complexity in Product Development Projects

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Abstract: This paper analyzes the relation between organizational complexity and the value of product development projects. For this end, an agent-based simulation that incorporates essential factors of complexity is used. During each simulation run, complexity is measured, and the project outcome is captured. Additionally, other behavioral measurements are collected to show the behavior on the agent level. Throughout different scenarios, the simulation differentiates between low and high task difficulty, segregated and integrated communication patterns as well as strict, chaotic, and decentralized organizations. The results of the analysis show, that higher complexity than the possible minimum is advantageous. For every simulated scenario, the optimal values of complexity are different. Overall, a certain amount of organizational complexity appears to be favorable for the project setup. Yet, exceeding this value is harmful to a project, which is consistent with the broad negative opinion towards complexity in literature.

Keywords: complexity, organization, organizational behavior, product development projects, agent-based simulation

1 Introduction

Since complexity affects all areas of product development (Götzfried, 2013), it continuously gains more relevance in research. Research areas include e.g. product complexity (Sinha, 2014), process complexity (Browning & Eppinger, 2002), organizational complexity (Rebentisch et al., 2016) or sourcing complexity (Novak & Eppinger, 2001). Yet, the widespread opinion among current research across different areas is similar: Complexity leads to a rise in cost, development time, and risk of project failure, and therefore needs to be reduced, avoided, or managed (Birkinshaw & Heywood, 2010; Carlucci, Lerro, & Skaržauskienė, 2010; Danilovic & Browning, 2007; Götzfried, 2013; Lissack & Gunz, 2005; Oehmen, Thuesen, Ruiz, & Geraldi, 2015; Qureshi & Kang, 2015). This paper recognizes certain harmful aspects of complexity. However, the overall negative stance towards complexity is questioned. The goal of this study is to challenge the purely negative view on complexity. Therefore, the following two working hypotheses are formulated:

H1: Complexity in project organization is not necessarily disadvantageous and therefore does not have to be reduced in every case.

H2: For certain project organization characteristics, a higher level of complexity other than the lowest possible level can lead to reduced project time and cost.

To validate the hypotheses, we examine organizational complexity through an agent-based simulation. An agent-based simulation is chosen for several reasons. First, by using a simulative approach, changes can be easily tested in the organization as a real organization would not allow. Additionally, due to its bottom-up character, emergent behavior can be observed in an agent-based simulation which is critical for complexity analysis. The simulation is not created by looking at the top-level system behavior but by modeling the members of an organization. Thus, new insights for the overall behavior can be gained that were not specifically modeled.

2 Theoretical background

This section summarizes findings and concepts of research regarding product development projects that are relevant to the created model. Then, the theory of organizational complexity is introduced, which forms the basis for implementation of complexity in the simulation and its measurement.

2.1 Product development projects

A product development project is a collection of interconnected activities by a certain number of people over a period of time with the goal to achieve parameters and characteristics of a new product (Clark, 1989). Turner (2008) calls a project an organization within an organization that has the ability to use assigned resources. Thereby, he references to the structure of a project which is very similar to an organizational structure. The similarity of structures stems from the project setup. The project structure is a combination of the organization and the pursued product (Eppinger, 2002; Sinha, 2014). The setup of the project has a strong influence on project success. There is a high linkage between organizational structure and the resulting product structure (Eppinger, 2009; Eppinger & Browning, 2012; Luna & Eppinger, 2015). Luna and Eppinger show a very high predictability of interaction between persons or teams by analyzing product structure. Morelli, Eppinger, and Gulati (1995) claim a predictability of interactions up to 80 %. Since the organizational structure is created first, the organization influences the product and not the other way around (Sosa, Eppinger, & Rowles, 2004).

In addition to the project setup, for a structured and effective project course, a defined product development process is needed. A process is defined as the sequence of certain activities with the use of information, knowledge and material resources (Lindemann, 2006; Ponn & Lindemann, 2011). Processes are made up of individual tasks with three different kinds of dependences between them: dependent, independent and interdependent (Eppinger, Whitney, Smith, & Gebala, 1994). Interdependent tasks have the most impact on complexity (see section 2.2). Thus, in the simulation of this paper, all tasks that are modeled are interdependent tasks.

A project always has one specific desired outcome, which is the main goal of the project (Clark, 1989; Turner, 2008, p. 2). Yet, reaching that goal can be achieved in multiple ways providing an additional set of parameters on project performance: cost, quality and time. These three performance goals are commonly visualized in the triangle of goals (Atkinson, 1999; Kerzner, 2013, p. 31). In his paper, quality is used as a defined model outcome. Cost and time are used to measure project performance.

2.2 Organizational complexity

The term “complexity” does not have an exact definition despite its widespread use (Schwandt, 2009; Weber, 2005). Sturtevant (2013) tries to illustrate complexity using the distinction between complicated and complex. He describes complicated systems as too big or too detailed for one single person to fully understand (Sturtevant, 2013). On the other hand, complex systems are characterized by strange behavior due to unanticipated interactions between elements (Sturtevant, 2013). The missing definition and the knowledge of influencing factors makes it possible to model complexity by including the influencing factors of complexity in the model.

Patzak (1982, p. 22f) focuses on the two factors variety and connectivity inside a system. In his definition, connectivity is composed of the types of relations and the number of relations. Variety, on the other hand, is described by the types and number of elements that are involved in a system. A more extensive look into complexity factors is provided by Steger, Amann, and Maznevski (2007, p. 4f). They describe complexity as a result of four different factors: diversity, interdependence, ambiguity and flux (Steger et al., 2007, p. 4f). Diversity is the plurality of number and types of elements which consists of the multiplicity and the variety of elements (Patzak, 1982, p. 22; Schwandt, 2009). It describes internal and external factors of a system. Therefore, even a simple system can experience complexity due to a diverse environment (Steger et al., 2007, p. 4f). Higher interdependence, generally, leads to increased complexity (Schwandt, 2009). Interdependence within a system is determined by the system structure. For example, modular systems generally have lower interdependence within the system than network structures. Ambiguity describes the uncertainty that comes from an unpredictable system. It is strongly impacted by the availability and clarity of information (Schwandt, 2009). Lastly, flux describes the rate of change of a system and its surroundings (Schwandt, 2009).

When it comes to complexity of systems, emergence is an additional element that needs to be addressed. Lissack and Letiche (2002) call emergence the difference between a system and the combination of its parts. Emergence are behavioral patterns or functions that occur when people or objects are combined together. Those patterns are different than the individual elements acting alone. It is a complex variety of simple rules of individual behavior that ultimately leads to emergence. The problem about dealing with emergence is the difficulty in predicting it (Lissack & Letiche, 2002).

For this paper, the general theory of complexity is adapted for organizational complexity. Dooley (2002) describes organizational complexity only as the variety of different elements in an organization. However, all four of the factors that describe complexity in general can be transferred onto organizational complexity (Rebentisch et al., 2016). They define eight clusters of factors that influence organizational complexity: Interdependence, operating standard procedure, objective or incentive alignment, information systems and tools alignment, location, personality, culture, and management hierarchy. These clusters are described in more detail in Rebentisch et al. (2016).

There are several methods of measurement for organizational complexity (Efatmaneshnik & Ryan, 2015; Sinha & de Weck, 2013; Vidal, Marle, & Bocquet, 2011). This paper uses the method by Rebentisch et al. (2016), which is based on the quantitative measurements of complexity by Sinha and de Weck (2013). Sinha and de Weck (2013) introduce the following formula:

$$C = C_1 + C_2 C_3 \qquad (1)$$

The complexity C is comprised from the component complexity C_1, the complexity of interdependence C_2, and the architectural complexity C_3. Yet, the complexity of single components in an organization would be the complexity of humans. Reliably quantifying the complexity of a human is questionable. Thus, for the measurement of organizational complexity, C_1 is not applicable (Rebentisch et al., 2016). In comparison to a product, an organization has intra-group and inter-group relations. Rebentisch et al. (2016) therefore adjust formula (1) to the following:

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

In this equation, the index *G* represents the group level and the index *O* stands for the organizational level. The indices *2* and *3* still express the complexity of the interactions and the complexity of the organizational architecture.

3 Methodology

This chapter describes the methodology used in this paper. First, the research questions of this work are presented. Then, an introduction in agent-based modeling is given.

3.1 Working hypotheses

The research study behind this paper aims to reveal insights about the influence of project organization complexity on the project value.

To verify the hypotheses posed in chapter 1, following research questions are addressed:

- Is there an optimal level of project organization complexity for maximized project value and which organizational characteristic does it depend on?
- Can certain forms of project complexity be used to systematically improve projects or are all forms harmful to projects?
- How should certain project characteristics be tailored to reach optimal project value?

3.2 Agent-based modeling

In agent-based modeling, the agents are modeled as conscious and independent individuals that are influenced by their environment and make their decisions based on a set of rules (Bonabeau, 2002; Macal & North, 2006, 2010; Rouse & Boff, 2005, p. 323). As agent-based modeling is a study of many individuals working together in a given structure towards a common goal, it is applicable for the study of organizations (Bonabeau, 2002; Epstein, 1999). The interactions between just a few agents with a simple set of rules can already lead to high complexity and unforeseen results (Gilbert & Troitzsch, 2005, p. 10). This is based on the so called emergent behavior (Epstein & Axtell, 1996, p. 33). Emergence is a phenomenon where interactions between objects on a lower level create an object on a higher level of abstraction (Gilbert & Troitzsch, 2005, p. 11).

The structure of agent-based models is typically made out of three elements (Macal & North, 2010): Agents, relationships between agents, and the agents' environment. To model these three elements, the Mesa library is used for this paper. It is a Python-based library that is specifically designed for agent-based modeling (Masad & Kazil, 2015).

4 Design of the agent-based model

For the model in this paper, two types of agents which comprise the development process are modeled: tasks and developers. The tasks are defined in the beginning and are worked on by the developers. The simulation is over when all tasks are completed. Each task and developer has a unique set of attributes which influence its actions. Developers move around in the artificial space and have the choice between working on tasks or communicating. Working on tasks has the chance of advancing the task progress or making a mistake which creates rework. Communication enhances the developers' knowledge. The choice is based on their personality which is made up of the following four characteristics: task allocation preference, tendency for disobedience and decentralized decision making, and knowledge of the project. Task allocation states the preference between working and communicating. Tendency for disobedience defines the probability of a developer to not act as defined by rules in an unproductive way. Decentralized decision-making leads to an action that is not defined, yet productive for the project. Lastly, knowledge of the project is one developer's specific knowledge of the project. The characteristics focus on the developer's behavior. A simulation process is developed which does not include the human thinking but rather the resulting decision-making mechanism.

In the artificial space, the distance between two developers' locations reduces the probability for communication. Additionally, the artificial space is used to model discovery of work. In development projects, work gets overlooked or is not discovered, leading to project delay. Tasks move randomly throughout the artificial space

The pattern of interaction between the developer agents in the simulation is defined by a Dependency and Structure Matrix (DSM). The interaction DSM is based on the DSM that describes the product architecture of the product being developed. As previously described, the product DSM and interaction patterns have very high congruence (Browning & Eppinger, 2002; Eppinger & Browning, 2012; Morelli et al., 1995; Sosa et al., 2004). If elements of a product are connected in a physical way or by any other type of interface, the chance of interaction between the responsible developers increases significantly. As described in section 2.1, Morelli et al. (1995) show predictability of interactions above 80 %. This makes the simplification valid to also use the product structure DSM as the definition of communication patterns in the organization.

The simulation is time based. In each step of the model, the same amount of time passes, and agents' actions are initialized. During each step, data is collected, and measurements are taken. Collected data include time, amount of work, rework, and communication, knowledge, task advancement symmetry, and the distribution of knowledge. The calculations are based on the measurement of organizational complexity from Rebentisch et al. (2016) and adapted to the numeric nature of the simulation. The most important measurement is organizational complexity. For this purpose, measured interdependence between developers is weighted with cultural complexity, interaction complexity, and allocation complexity. This calculation forms a complexity heat map. All entries of the heat map are then summed up and multiplied by the architectural complexity of the communication pattern based on the numeric complexity measurement of Sinha and de

Weck (2013). This leads to a single value measurement of organizational complexity that incorporates the influencing factors of complexity.

Another calculated measurement is the value of a project. As shown previously, project success can be measured with three dimensions: quality, time and cost. In this model, quality is defined to be equal in every model run, as a simulation is finished when all tasks are done with satisfactory quality. The measurement of quality is therefore not applicable. The two measurable dimensions of the project triangle are combined. The project value is defined as a standardized measurement on the scale of zero to one. Both, duration and cost, are weighted equally and comprise half of the value. The increase of both parameters is negative for project value.

5 Results

The main result lies in comparing different projects and how various organizational behaviors perform for those projects. This paper tests four different project types and three different organizational behaviors. The four projects are constructed by combining two factors: task difficulty and the type of interaction-DSM. The different test cases are shown in Figure 1. The strict organization is defined to operate very close to the guidelines. Developers allocate work as they are told. The chaotic organization sets itself apart through high developer free-will and the high resulting uncertainty. Lastly, in the decentralized organization, developers are encouraged to do the work that is smartest from their perspective.

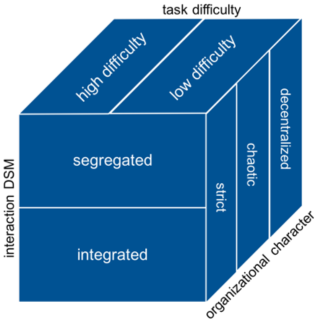

Figure 1. Combination of four different scenarios (interaction DSM and task difficulty) and the three different organizational characters (own illustration)

Analyzing the overall project value over the organizational complexity in Figure 2, it is shown that there is an optimal project value for the simulated projects. On the left side of the figure, the blue lines represent the integrated interaction DSM, whereas the orange lines show the segregated interactions. The lighter shading displays the low difficulty projects and the more saturated lines indicate higher difficulty. Since the outcome of all simulations is assumed to be equal, the more difficult projects have a lower value. They result in the same outcome with higher effort. The segregated scenarios demand more complexity for the optimal project value. This leads to the answer of the first research question. The maximum of the graph suggests a maximum of project value. The different curves show the dependability of that optimal value on a variety of project factors, including project difficulty and interaction patterns.

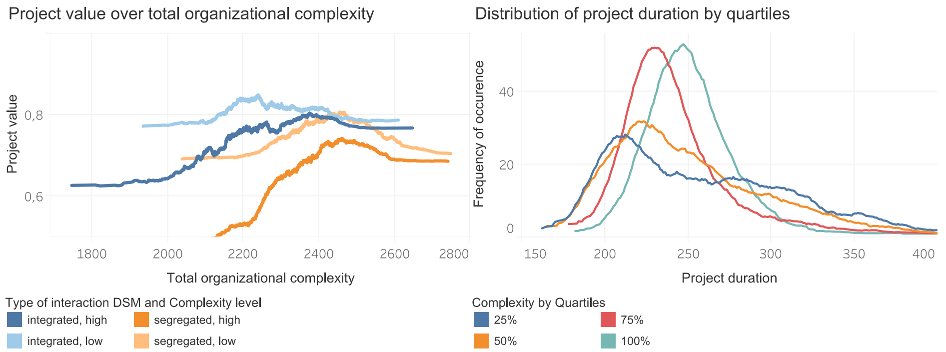

Figure 2. Influence of organizational complexity on project duration

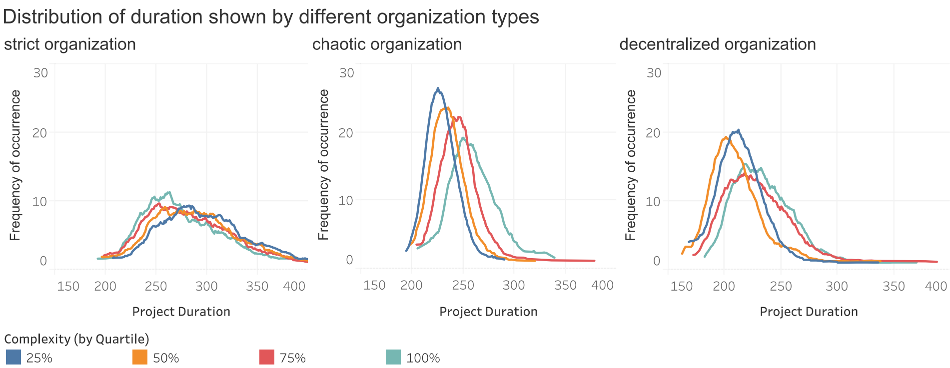

Figure 3. Different levels of complexity are optimal for the various organizational behaviors

On the left side of Figure 2, the frequency of occurrence of different project durations sorted by complexity quartiles is shown. In Figure 3, the three different organizational behaviors are shown in the various graphs. For the strict organization, the highest complexity quartile performs best. For the chaotic organization, the quartile with the lowest complexity achieves the best results. Yet, these two organization types are on the opposite sides of the complexity spectrum. The strict organization holds minimum complexity, thus striving for a higher value for lowest project duration. Opposite can be said for the chaotic organization. The decentralized organization shows the optimal result for the quartile with the second lowest complexity. The decentralized organization has a medial complexity. This leads to the optimal project duration of the medial complexity quartile. The results show that a balanced organizational complexity delivers best results. Hence, reducing complexity is not necessarily beneficial.

In Figure 4, single factors are analyzed. The possibility of disobedience shows a project duration minimum around 20-25 %. The probability of decentralized decision making leads to a decrease of project duration up to a probability of approximately 30 %. After that threshold, the effect of a higher probability is receding. These two examples of single factor optimization show the potential of improving the setup of product development projects.

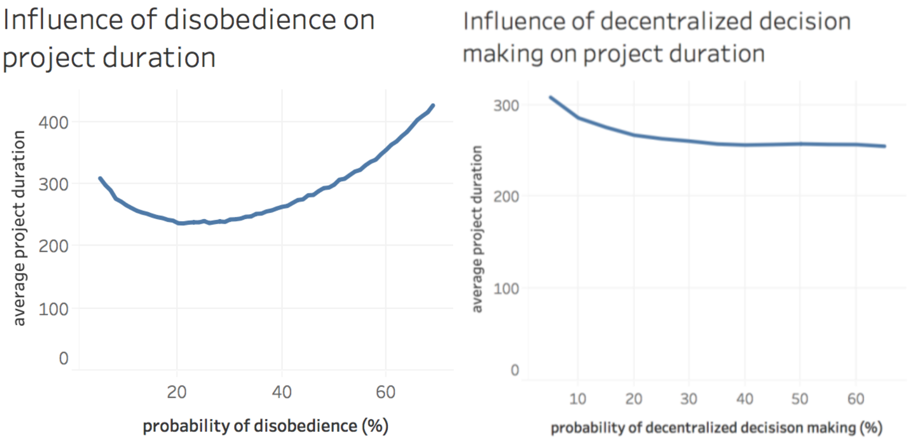

Figure 4. Influence of the probability of disobedience (left) and decentralized decision making (right)

These results deliver an answer on the second hypothesis. It can be shown that specific changes to a project can improve its outcome even though complexity rises. Thus, the least possible amount of complexity is not necessarily the optimal value. The results of Figure 4 show the potential for optimizing single factors of a project. Both analyzed factors increase the project complexity significantly, and up to a certain point, also improve project performance.

6 Conclusion

Organizational complexity influences the value of a product development project. Contrary to Birkinshaw and Heywood (2010); Carlucci et al. (2010); Danilovic and Browning (2007); Götzfried (2013); Lissack and Gunz (2005); Oehmen et al. (2015); Qureshi and Kang (2015), the increase of organizational complexity does not necessarily lead to a decrease of project time and cost. In a series of experiments, this paper suggests that there is an optimal value of organizational complexity for a project. Therefore, the increase of the right complexity drivers to reach that time and cost based project value leads to an improved project progression. Yet, it is also shown that the increase past this optimal point is harmful to the project. The simulation runs with different project scenarios and organizational behaviors all lead to different optima. Thus, not a general optimum for complexity can be stated but it is specific to each project. Both working hypothesis are therefore proven to be correct.

It is to be mentioned that this is not an exhaustive study. The goal of this paper is to present a different perspective on complexity. The presented findings demonstrate a unique approach to analyzing complexity from a different view point. Additionally, the simulative character of this paper does not enable a complete consideration of complexity. For example, the complexity through the human factor is not included. Results of this simulation can only be transferred carefully to real-life situations. Testing the simulated results in real organizations would be a next step in investigating the real-life project value of complexity.

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