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Method for the Evaluation and Adaptation of New Product Development Project Complexity

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Abstract

This paper presents a method that enables project managers to evaluate the complexity of an intended new product development project and adapt it to ensure fit with the organization's capacities and the project setting. Central hypothesis is that complexity drivers of the project are causing resource consumption and thus costs. Therefore, a systematic evaluation of complexity drivers and their subsequent demand placed on the resources of the organization for each activity of the project needs to be conducted. For this purpose a novel approach based on a resource-oriented process cost calculation method has been developed. The approach includes a consideration of uncertainties regarding the complexity impact and definition of a capacity to tolerate complexity. Consequently, by analyzing the project's complexity for its cost and resource impact as well as comparing it with the organization's capacities, planners are able to identify critical complexity drivers upfront that would disrupt project execution and develop countermeasures.

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Keywords:

1. Motivation

Companies operate now in an environment that has substantially changed during recent decades. Besides increasing globalization and the following international competition as well as more volatile international markets, a shift from a seller's to a buyer's market is often observed [1]. Customer demands are increasingly heterogeneous, differentiated and sophisticated. To meet these demands and stay competitive, companies regularly react with the introduction of new products, a higher product variety and shorter product life cycles [2]. The development of new products is thus essential for the success of an organization and driver of corporate growth [3]. Therefore, research relating to product architectures and complexity has been conducted. More recently, the corresponding development organizations as well as the organizational complexity of product development projects have been of interest [4,5].

An increasing amount of work in corporations is carried out via projects [6,7]. As a result, some scholars observe a "projectification" of the firm and the business environment [6]. Others claim that "we live in a projectified world" [7].

In spite of the importance of new product development projects, cost overruns, missed deadlines and specifications are problems that can be observed frequently [8].

While multiple reasons for poor project performance can be identified, one underlying reason, mentioned by researchers as well as practitioners, is the increasing complexity of projects [10,11].

2. Introduction and fundamentals

The goal of this paper is to present a method to evaluate the complexity of an intended new product development project upfront as well as adapt it to ensure fit with the organization's capacities and thus achieve a better project performance. To understand the impact of complexity and the demands placed on the resources of the organization one must systematically examine the link between the two domains.

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2.1. Complexity

Complexity is frequently named as a reason for poor project performance [10,11]. However, there is no generally accepted definition of the term "complexity" itself [12]. From a system theory viewpoint, complexity is often defined as a system feature, which is determined by the number and the variety of its elements and their relationships to one other as well as their dynamic changes [13]. Since projects can be characterized as systems [14], this understanding of complexity is adopted for this work.

2.1.1. Project complexity

Similarly, to the term complexity, there is currently no agreed upon definition of the term project complexity even though research has been conducted over years [14].

GERALDI [15] found out when inquiring about project complexity with practitioners that it is "something […] that made a project unique, more complicated and more difficult to execute, manage and control […]". VIDAL ET AL. [14] proposed a definition, which is similar to the findings of GERALDI, highlighting that complexity is a feature that can be used to characterize a project and that it is affecting project management. They postulate [14]: "[..] project complexity is the property of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given reasonably complete information about the project system. Its drivers are factors related to project size, project variety, project interdependence and project context". The present work will follow this definition and understanding.

2.1.2. Measurement and evaluation of complexity

One can differ fundamentally between two possibilities to measure or evaluate complexity. The first and *direct* option is to use a measured value, which determines a complexity degree. The second and *indirect* option is via economic effects of complexity [16].

An overview of direct approaches focussing on measuring project complexity can be found for instance in VIDAL ET AL. [17]. While there are challenges in measuring complexity directly, one can use complexity drivers to make statements about the level of complexity in organizations [18].

Complexity drivers can be understood as a phenomenon that is causal for the (increasing) complexity of a system [19]. Other authors, using synonymous terms instead of complexity driver, have a similar understanding. [10,18,20]. For example, MARLE and JABER [10] use "factors" to answer what "makes a project more complex" and to assess how these factors "contribute" to project complexity.

Based on RENNEKAMP [18], complexity drivers are defined in the context of this work as "plurality of external and internal factors, which increase the complexity of a project and can be used for indirect evaluation of the project complexity level".

2.2. Operationalizing Ashby's law of requisite variety

A product development project can be characterized as an open system, as such, its complexity should be considered in dependence of its environment [19]. Following the "law of requisite variety" postulated by ASHBY [21], who stated that "only variety can destroy variety", this translates into the requirement that the internal complexity of a system has to match the external complexity [19]. If one transfers ASHBY'S Law into practice, this means for example, that the more complex the product program and markets are, the more complex the organization and in consequence its coordinating processes have to be [16]. The assignment of e.g. an engineer to a product development project means building up internal complexity. Building up internal complexity results in additional costs, but on the other hand enables to better react to external complexity, which is complexity stemming from the project environment. Examples are complexity drivers relating to customers, markets or technologies [19].

While the measurement of varieties (or complexities, when understanding variety as a measure of complexity) is hardly possible in practice, the idea and term are essential, because it is about harmonization of comparative factors [22].

In summary, one can conclude that it is necessary to evaluate the complexity of a project in the context of the surrounding project setting (and external complexity) and adapt it reciprocally. But project managers and planners have to further consider the capacities of the organization to tolerate complexity. These capacities are operationalized in the present context by the limited resources and/or budgets of an existing company.

3. Related research

There are a number of comprehensive project complexity frameworks, which enable their users to identify factors that drive the complexity of a project. But these approaches often conduct only a qualitative assessment of complexity in a project and don't build a bridge between complexity and its implications for the organization in terms of costs and resource demand [10,20,23].

On the other hand, numerous attempts to quantify project complexity through mathematical models have been attempted in research. With these models, one is able to directly measure complexity, but systematically tracing back these evaluations to resource demand is not part of their work [5,17,24]. REBENTISCH ET AL. [5] focusing on organizational complexity in product development projects, state that if their calculated complexity score surpasses a "complexity capacity" an organizational redesign should be performed. But it is noted that this "complexity capacity" still needs to be developed.

Approaches which aim to link complexity to performance figures in companies, took a process perspective to operationalize the term complexity via complexity drivers [16,18,25]. However, these approaches focus on specific facets of complexity in companies. Thus, identifying the relevant complexity drivers is not part of their work [25] or they focus on a limited number of complexity drivers in companies [18], or specific processes in companies [16].

As a result, there is a need to develop a method to systematically evaluate the complexity of product development projects via complexity drivers and their quantitative impact on the resources of the organization in a given project setting – under consideration of the capacities of the organization to tolerate the project's complexity with its available limited resources.

4. Method to evaluate and adapt the complexity of product development projects

The main research question during the development of the method was: "How can one evaluate and adapt the complexity of new product development projects to ensure a fit with the organization's capacities?"

4.1. Assumptions and limitations for the method

In the application of this method it is assumed that a reference product development project is available. For this reference project, resource estimations for all product development activities need to exist. The present work therefore aims at explaining the resource demand caused by additional complexity, which impacts the planned project in comparison to the reference project. Project managers thus need to review the intended project against the background of those complexity drivers, that exhibit different characteristics compared to the base case project or those complexity drivers that can occur additionally.

4.2. Overview of the method

The proposed method to evaluate and adapt the complexity of a NPD project follows an iterative approach, which is depicted in figure 1. The starting point is the project plan with its activities based on the reference project. In the next steps, for each activity, relevant complexity drivers and resources are qualitatively identified and assessed. Subsequently, the impact of the additional complexity of the intended project onto the estimated resource demand is evaluated, under consideration of uncertainties, for each activity respectively. The results are then aggregated over all activities and compared with the capacities of the organization. Thus, decision makers are able to identify critical drivers of complexity and develop countermeasures. The countermeasures are implemented in the following and if necessary, a revaluation of the project complexity is conducted to simulate and validate the effects of the measures.

4.3. Identification of relevant complexity drivers

To support the identification of the relevant complexity drivers for the required activities, a complexity driver catalogue was compiled. The complexity drivers of the catalogue were identified through an extensive literature study in the research areas of complexity management and project complexity.

The catalogue is structured into three hierarchical levels. The first level represents the general category of the complexity driver. Within the first level the categories environment, product, organization and technology & resources were used to organize the findings from the literature review. The next level in the hierarchy contains additional sub-categories in which the complexity drivers are classified.

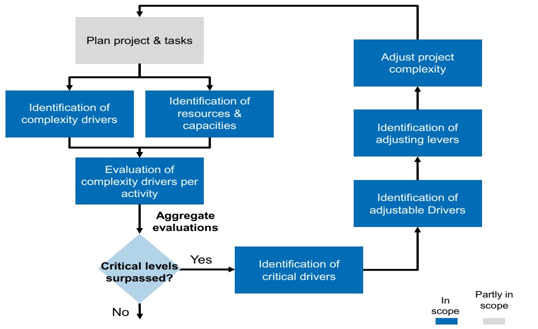

Fig. 1. Overview of the method

Figure 2 shows an excerpt of the developed catalogue. In total 87 drivers were identified. There is no claim to completeness since every project has likely unique characteristics, challenges and project settings. The complexity driver catalogue can therefore be seen as a basis for company and project specific adjustment.

Every project activity is assessed using this catalogue to identify those complexity drivers that can cause additional resource demands relative to the reference project. The catalogue is thus intended to be used as a template for all activities and its final version should be agreed upon before the complexity evaluation of the project by the teams is conducted.

Category	Subcategory	Complexity driver
Environment	Customers	Location of the Customer
	…	…
Product	Product structure	Degree of novelty of the product
	…	…
Organization	Organizational structure	Number of involved organizational units
	Operational structure	Dependencies between schedules
	…	…
Technology & Resources	Technology maturity level	Degree of maturity of technologies
	Technology variety	Number of information systems
	Resources	Number of projects sharing their resources
	…	…

Fig. 2. Excerpt of the complexity driver catalogue

4.4. Determination of relevant resources and costs

A Resource Breakdown Structure (RBS), provides the required input data to evaluate the activities regarding the complexity impact. The RBS lists in a structured and hierarchic manner the resources that are needed to successfully execute a project [26].

The presented method is able to model an unlimited number of resources per activity and complexity driver. This means that for each occurring complexity driver in an activity, more than one impacted resource can be assigned to it and its impact modeled. By structuring the resources in a hierarchic manner, one can also aggregate the sub-categories of the resources, if required, to reduce the modelling efforts.

One major advantage of the resource-oriented process cost calculation method is the separate collection and modelling of cost and resource consumption rates. It is possible, for instance, to model increasing cost rates in comparison to previous projects [25].

4.5. Estimating the impact of complexity on resources

Central hypothesis of this work is that complexity drivers of the project are causing resource consumption and thus costs. In order to be able to analyse where the complexity of a project emerges a process perspective on the project is used.

It is assumed that for a process step (activity), the relevant complexity drivers can first be identified, then evaluated regarding their indicating values as well as their possible ranges. Subsequently they are assigned to the resources they are impacting and by how much. For these steps, the resource-oriented process cost calculation method (RPK) developed by SCHUH will be adapted [25]. For a detailed explanation of the RPK method the reader is kindly referred to the work of SCHUH [25]. The central relevant elements and required adaptations of the RPK are described in the following.

The first adaptation of the RPK method is that several complexity drivers are allowed per activity instead of just one as is the case with RPK. The second adaptation is that internal as well as external project complexity drivers are modelled – in particular also organizational and environmental drivers in contrast to product and variant related drivers, which is the focus of RPK. The third adaptation of RPK, which is necessary because of the application of the method in the early planning phase of the project, is the modelling of uncertainties regarding the impact caused by complexity drivers with a stochastic distribution [25].

The following figures 3 & 4 illustrate the hypothesis and approach based on the assumptions outlined for this method.

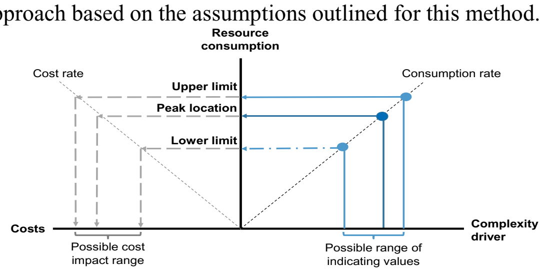

Fig. 3. Uncertainty of a complexity driver's impact

Figure 3 visualizes the link between one complexity driver and its consumption of one resource under consideration of uncertainty. As depicted in the figure with the black dotted line in the right half of the graph, it is assumed that an underlying consumption rate for each complexity driver exists. On the right part of the x-axis, the possible range of the characteristic value of the complexity driver, which can occur in the project is indicated by the blue bracket. On the y-axis the range of the corresponding resource demand caused by the complexity drivers is plotted.

There will be in most cases an uncertainty regarding the impact, which a complexity driver will have on the resources. These uncertainties are modelled in this method with a triangular distribution. For each driver, the lower limit, the peak location and the upper limit need to be determined in the unit of measurement of the affected complexity driver. This assessment should be done by experienced staff members and wherever possible under usage of historic data and experiences.

In some cases, especially in first applications of the method, the underlying resource consumption rate due to the complexity drivers may be unknown or the derivation of the consumption rates requires too much effort. Therefore, one can simplify the evaluation of the complexity impact onto the resource and only estimate the three points of the triangular distribution (lower limit, peak location and upper limit) directly for the resource demand induced by the complexity driver. The underlying estimated consumption rate may be approximated after repeated application of the method.

This facilitates the application of the method and decreases the required data collection efforts to run the evaluations. The method allows in this case, to describe the complexity driver verbally instead of measuring it along a driver specific scales. Subsequently, the impact of the complexity driver can be directly determined by a triangular distribution for the estimated resource consumption in the unit of measurement of the resource. Deriving the positions of characteristic values on the driver specific measurement scale and the underlying consumption rate becomes therefore dispensable, but is encouraged to improve comparability between projects.

In the left part of the graph in figure 3, the corresponding cost rate of the resource and the subsequent estimated range of the cost impact of the complexity driver can illustrated and read off.

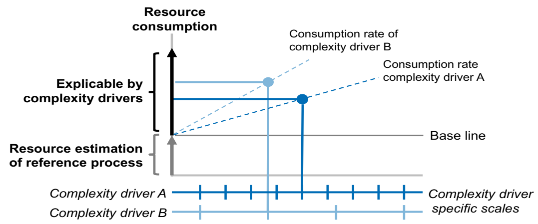

Fig. 4. Linking complexity to resource demand

Figure 4 depicts for one activity and one resource the impact of two complexity drivers A and B. Uncertainties are not pictured for reasons of simplicity. On the x-axes the complexity drivers are captured. In this case, two drivers are relevant. These complexity drivers have driver specific scales indicated here by the blue and light-blue x-axes. The y-axis shows the consumption of the resource. The activity has, based on the reference project, a base line for the demand of the examined resource, illustrated here by the horizontal grey line. The identified complexity drivers A and B of the new project are causing an additional estimated demand of this resource. This resource demand results from multiplying the characteristic indicating values of the complexity driver with the underlying driver specific consumption rates.

For the present method, an additive approach was chosen to model the resource impact of more than one complexity driver onto one resource. This means that the resource demand caused by complexity drivers are independently estimated. Possible interdependencies between complexity drivers are thus neglected. In figure 4 the additive impact is indicated by the black arrow above the base line on the y-axes, which is the sum of the demands of complexity drivers A and B.

4.6. Evaluation of the overall project complexity

In order to be able to make statements about the overall complexity of the product development project, and to be able to derive conclusions, if the complexity requires resources beyond the available or planned capacities, the results of the data collection and evaluations of the activities need to be aggregated over the whole project.

The identified drivers and their estimated resource demand distributions for all activities are therefore merged into standardized data input matrices in Microsoft Excel®. The structure of the input matrix for one activity of one team is shown in figure 5. The three first columns are formed by the complexity driver catalogue, that was explained above. Because this catalogue is used as a template for all activities, the next column describes if the driver is relevant for the evaluated activity. In the fifth column the resource is entered, which the complexity driver impacts. The triangular distribution of the resource demand estimation is entered in the last three columns. If a driver impacts more than one resource, the last steps are repeated in the same manner in the following columns for each respectively.

The data input matrix in figure 5 illustrates the simplified explanatory model, in which the impact of complexity driver is captured verbally without measuring it alongside the driver specific scales and modelling of consumption rates.

			Process ID number					
			Process name					
			Process type					
			Contribution by: Department name 1,..					
			Interface with: Department name 2,..					
Category	Sub category	Complexity driver	Driver relevant (Y/N)	Resource affected	Lower limit (in hours)	Peak location (in hours)	Upper limit (in hours)	
Environment	Customers	Location of the Customer	Y	1	2	4	6	

Fig. 5. Data input matrix for one activity

The project complexity evaluation model, which aggregates the results, was implemented with the software MATLAB®. The data from the input matrices in Microsoft Excel® are read in and through Monte Carlo simulations the estimated complexity impact ranges on resources and costs under consideration of uncertainty can be simulated.

The first simulation of the project complexity evaluation model is to evaluate the impact of complexity at the activity level. By using Monte Carlo simulations, for every resource that is relevant for the examined activity, histograms can be plotted that depict the possible resource demand scenarios caused by all complexity drivers affecting the resource. This helps to identify those activities in a department that may be particularly vulnerable to the impact of complexity.

The second simulation of the project complexity evaluation model is at the department (or team) level. This means that aggregated over all activities and complexity drivers in the department, the frequency distribution of the additional resource consumption of the considered resources is calculated and plotted. Therewith, one is may be able to identify whether exceeding existing capacities becomes likely. Multiplying the estimated resource demands with the respective cost rates provides a means of assessing the possible cost impacts of complexity per department.

Finally, one can analyse through simulations over all teams and their activities, which complexity drivers are affecting which resources of the project and by which estimated magnitude and probability. Thus, the most critical drivers of project complexity can be derived and ranked by their impact.

Once the complexity of the project is analyzed regarding its possible resource and cost impacts, project planners have to decide whether or not critical values of complexity that the current project organization could tolerate will be exceeded.

4.7. Derivation of adaptation measures

If the project managers conclude that tolerable complexity values are exceeded, the derivation of adaptation or counter measures become necessary. According to WILDEMANN [27] three general impact directions can be differentiated in complexity management: complexity reduction, complexity mastery, complexity avoidance. Additionally, increasing complexity can be a fourth impact direction [13]. Alongside these four main strategies a, guideline on how to derive project complexity adaptation measures and a catalogue with measures are currently developed, which will support managers in identifying counter measures for critical complexity drivers.

5. Case study

The method has been applied with empirical data from a medium sized company in the mechanical engineering sector with its headquarters and main factory in Germany. The company develops and produces electro-mechanical machines for international markets. The data collection was conducted prior to the development of the method with a slightly different aim. Thus, minor data adjustments were needed. The application provides therefore only a first partial validation of the method and further applications in different companies and industries are necessary to overcome this research limitation.

Through structured interviews with the departments a reference development project was established, consisting of the activities and their resource demand for all units. For each activity it was determined, if complexity drivers exist, that can cause additional resource demands as well as their likelihoods of occurring. The analysis was conducted without a predefined list of drivers. Therefore, it was necessary to abstract certain drivers to be able to fit them into the developed generic complexity driver catalogue. 15 complexity drivers were identified after the aggregation. Additionally, the complexity drivers and their impact were not identified alongside complexity driver specific scales, but captured verbally. Thus, the derivation of resource consumption rates and their nomograms were not possible.

Figure 6 depicts a histogram of the additional resource demand for one of the departments calculated with 40.000 Monte Carlo realizations. The additional resource demand, which can be caused by complexity drivers, has a possible range from 105 hours to 530 hours. The base line resource demand for the reference processes lies at 604 hours.

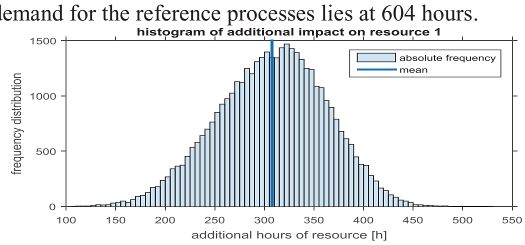

Fig. 6. Total impact on resource 1

Figure 7 shows the possible scenarios of project complexity in relation to the base case for the whole organisation. In the worst case scenario, excess resource demand caused by additional complexity is equivalent to 51% of the baseline resource demand. In the most likely case, excess resource demand caused by additional complexity is equivalent to around 25% of the base line resource consumption.

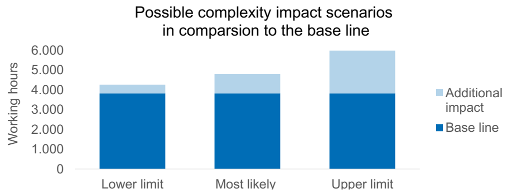

Fig. 7 Complexity impact scenario

6. Conclusion

The presented method enables managers to evaluate and adapt the complexity of new product development projects to ensure a fit with the organization's capacities.

A resource-oriented process cost calculation method was adapted to systematically link the impact of complexity to resource demand under consideration of uncertainties. The project complexity evaluation model was implemented in Microsoft Excel® and MATLAB®. Using Monte Carlo simulations, the overall possible impact scenarios of the identified complexity drivers can be evaluated. A comparison of the frequency distributions of the total resource demands with the capacities of the organizations enables managers to identify possibly critical complexity drivers. Subsequently, the derivation of adaptation measures and an assessment of their effectiveness is feasible.

The method has been applied to a test case with empirical data from a manufacturing company. The application verified that the method can feasibly be used to estimate the impact of complexity and identify the most critical drivers of the project. However, research limitations currently exist. One limitation is the model's restriction to triangular distributions. Another is the assumption of additive complexity driver impacts.

Further research should also explore adapting and implementing the findings into a model with interdependent activities. Validating the possibility of deriving resource consumption rates for complexity drivers is another necessary step. One guiding question would be whether the additional modelling efforts are justified by improved estimates regarding the complexity impact.

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