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Assessment of Changes in Technical Systems and their Effects on Cost and Duration based on Structural Complexity

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Abstract

Large engineering products like naval vessels are very complex systems. As there are long development times, multiple design changes occur frequently because of changes in requirements. This leads to cost and schedule overruns. One reason for these failures may be a lack of understanding the effects of changes in engineering projects due to their complexity. Therefore linkages between requirements, functions and components involved in changes must be analyzed to predict these effects. This paper presents a method to determine the impact of changes on product cost and project delay due to varying levels of complexity and to evaluate change alternatives.

Keywords: Structural Complexity; Complexity Measurement; Technical Changes

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1. Introduction

The past has shown that numerous large engineering projects resulted in cost and schedule overruns [1, 2]. Changes that seem small on the first sight often lead to substantial product adjustments. It is obvious that with increasing project size more problems are likely to occur. Today's highly complex projects with a global supply chain and various production locations lead to a level of complexity that distracts from the project itself. There could be technical dependencies, process dependencies or organizational dependencies. If changes are made, there is a high possibility for mistakes. Even though there are some countermeasures [3, 4, 5] such as a modular system that keeps a technical change easy, there is still a high possibility for mistakes. In the naval context it has been frequently recorded that even small changes caused big effects and as a chain reaction the whole project might be affected by one little change [6, 7]. An important contributor to this is the complexity of a product. Therefore it is necessary to understand the effects of changes on the structural complexity and to find a method that makes decisions and their effects on complexity more predictable.

After having presented the statement of the problem in section 1, section 2 gives a short overview of fundamentals, related work and the research aim. In Section 3 the method for the assessment of changes in technical systems and their effects on cost and duration based on structural complexity is presented. Section 4 shows the results of an application of the method. The last section provides the conclusions of this paper.

2. Fundamentals and related work

This section provides an introduction into the fundamentals and related work. Further the research aim is defined.

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2.1. Different types of complexity

Complexity can be divided into several subcategories. According to SCHUH and SCHWENK [8] there is an internal and an external complexity. The internal complexity is the complexity that is created through an increase of product variants due to the coverage of the market demands. The external complexity results from the market side, and is thus dependent on demands of costumers, norms, laws and competitors. Furthermore, there are three dimensions of internal complexity, namely the structural complexity, the dynamic complexity and the organizational complexity as shown in Figure 1 [9]. Structural complexity is representative for the system's architecture and dependent on the physical design of the system. Structural complexity can be broken down into the components complexity, complexity of the interfaces and topological complexity. The deep blue colored boxes represent the focus of this research.

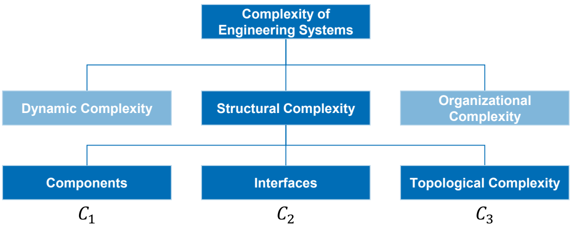

Fig. 1 Types of complexity and breakdown of structural complexity elements

2.2. Design structure matrix approaches

One way to manage the complexity in product architecture design is the design structure matrix (DSM) according to DANILOVIC and BROWNING [10]. The method has been used for many years and it has been shown that it is an effective tool for "representing and analyzing the architecture of an individual system such as a product, process or an organization" [10]. The method helps to illustrate dependencies between components or functions. A component based DSM is used for modelling a system's architecture that is based on components and subsystems and their relation to each other [11, 12].

The DMM (domain mapping matrix) approach is a further development of the DSM. DMMs provide a framework that distinguishes between single- and multi-domain interactions across domains. These multi-domain interactions can be further used to detect interactions and dependencies between functions, requirements and components. With the help of DSM and DMM approaches, it is possible to develop an analytical/computational system representation and further trace the dependencies between the different domains.

2.3. Measurement of structural complexity

The possibility to measure structural complexity in this context is mainly based on the work of SINHA and DE WECK [9, 13]. They developed an algorithm that quantifies the structural complexity in a generalizable manner. Although their research focused primarily on software-intense hardware systems, the factors were modified by DOBSON [14] to suit a naval maritime system.

As a basis for analyzing effects of changes, the method for quantifying structural complexity was chosen due to its generalizability of an application in engineering systems. SINHA and DE WECK validated their method for a broad range of different systems, including highly complex systems like satellite or aircraft engines as well as systems of low complexity like hairdryers or electric drills. The structural complexity is described in an equation as follows [9, 13]:

$$\text{Structural Complexity } C = C_1 + C_2 C_3 \qquad (1)$$

Where C_1 is component complexity, C_2 is interface complexity and C_3 is topological complexity. The structural complexity metric is defined by SINHA using the following analytical form [9, 13]:

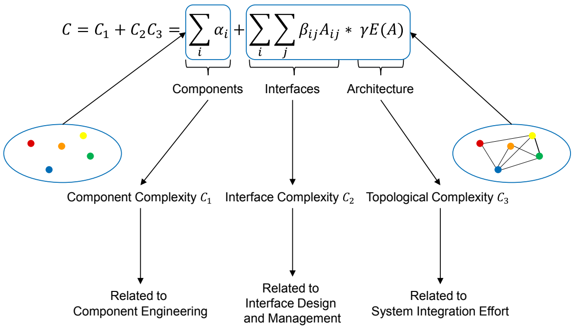

Fig. 2 Structural complexity measurement formula [9] [13]

2.4. Effects of structural complexity

Various studies describe the effects of structural complexity on cost or duration and have been evaluated for this research. As proposed by SINHA and DE WECK [9, 13], a single variable model uses the structural complexity as a predictor of cost and effort. In their research they considered the correlation of structural complexity and cost as well as the relationship between structural complexity and duration. They discovered a high correlation between cost and complexity, defects and complexity, as well as between mean build time and complexity.

DOBSON [14] calculated in his study the structural complexities of subsystems in navy ships using the method of SINHA. He proved a high correlation between costs and complexity. His findings are used as an important pillar for this research. NASA studies [15, 16] regarding comparable space missions and systems showed a relationship between cost and time and further demonstrated an exponential increase of cost and development time in dependency to complexity.

Although it cannot be predicted that one unit of complexity results in 1 dollar costs and/or one hour of change effort, it can be accurately predicted how the curve will behave and that costs are highly correlated with complexity. Furthermore, it was deduced that cost exponentially increases with rising complexity. Durations showed a similar behavior in the studies. Due to the relationships between cost and time, it can be deduced that both have an exponential behavior in their correlation with complexity.