A method to set up a complexity index to improve decision-making performance.

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Abstract

Engineering companies face the challenges of increasing product variety and technology induced increasing complexity of products. If the company is not able to manage this complexity within the design process it will cause productivity losses and rising complexity costs along the value-chain. Lack of information and information asymmetries lead to sub-optimal decision-making and thus to sub-optimal product-production-system designs. Companies struggle to evaluate product designs out of a broader, multi-functional perspective to derive the optimal design for the customer and company. The central question which needs to be solved is how companies can overcome these disadvantages in the early stages of product and process development. Based on the existing product design assessment methodologies proposed by academic and industrial communities this paper addresses these problems by developing a novel concept to improve decision-making performance in the early design phase by integrating the complexity perspective into decision-making. The paper delivers a guideline how to build up a complexity index to condense complex information.

1. Introduction

1.1. Problem and research relevance

Making the right decisions within early development design phase is a complex problem [1]. Multiple system elements and interdependences, uncertain and changing information, dynamic opportunities, multiple goals as well as the consequences along the life cycle need to be considered. Garvin and Roberto [2] state that "decision-making is arguably the most important job for the senior executive and one of the easiest to get wrong". Product design decisions in manufacturing companies result in allocations of resources to achieve certain objectives [3]. Companies seek to increase the level of rationality in the decision-making processes [4]. This is realized by using more information and by integrating multiple perspectives. Researchers criticize that most decision-making approaches over-simplify the issue of decision-making. This paper will explain a methodology how companies can systematically built up a complexity management system to improve the evaluation of complex problems and thus their decision-making performance. Researchers as well as practitioners agree on the significance of having well-defined decision criteria [5].

1.2. Context of the study

The introduced methodology will be explained along the test development decision-making of a semiconductor producing company. Figure 1 shows an excerpt of the product structure of the interface board of the testing solution.
The test solutions contain different hardware and software components which are linked to product, customer as well as production process constraints and requirements (s. figure 2). Hence choosing the optimal test solutions (in terms of costs, speed and quality) for the variety of products and diversity of requirements is a complex challenge due the high number of interdependencies. Chapter 2 presents a review of different evaluation concepts to support the decision-making.

2. Existing approaches to evaluate product designs

2.1. Complexity evaluation concepts

Different approaches are carried out in research to evaluate projects (see Table 1). A typical scorecard for the decision to go to development is introduced by Cooper [6]. This scorecard contains different decision-making dimensions like strategic fit and importance, product and competitive advantage, market attractiveness, core competencies, technical feasibility and financial risk.

Table 1. Existing evaluation approaches to support decision-making.

| Approaches                          | Author                                      |
|-------------------------------------|---------------------------------------------|
| Scorecard                           | Cooper (2009, p.51) [6]                     |
| Design for variety                  | Martin & Ishii (1996) [7]                   |
| Product complexity effectiveness    | Schuh et al. (2010) [8]                     |
| Product portfolio complexity measurement | Orfi et al. (2011) [9]                      |
| Optimal variety                     | Rathnow (1993), p.42 [10]                   |
| Variant mode and effect analysis    | Caesar (1991), p.36 [11]                    |
| Variant tree                        | Schuh & Schwenk (2001) [12]                 |

Going a step deeper in the hierarchy level, the evaluation of product architectures can be done with the design for variety methodology [7]. Coupling indices are defined based on the engineering characteristics to reveal modularization and standardization potentials. They are used to evaluate the implementation of the product architecture and support the definition towards the optimal design. The approaches by Schuh et al. [8] and Orfi et al. [9] contain different indicators to evaluate the product-process design out of different perspectives in order to reveal optimization potential. For the evaluation of the technical implementation of a project based on the requirements, different indicators are introduced in the research community. The evaluation of the complexity of product architectures can be conducted with products per function [13], commonality index [7], the dependency index [14] or the general complexity index (GCI) [15] to assess the complexity of different product architecture designs and to enable a systematic and objective comparison.

The common idea behind these different approaches is to integrate different information into indices to make it transparent, comparable and usable for decision-making. Thus the major goal of it is to improve the information basis for decision-making. It builds the systematic bridge between system elements and information streams which are scattered along different functional departments. Thus complex problems become more tangible for decision-maker.

2.2. Complexity drivers within decision-making of product and production process designs

Several researchers have identified complexity drivers for manufacturing companies which have an impact on the decision-making performance. These indicators can be used to evaluate product and process design effectiveness. Different functional departments are affected by these drivers. Table 2 illustrates some of these drivers and potential indicators to measure the complexity. Hereto belong for instance the number of SKUs, the number of functions or unique parts implemented in the product architecture, the demand variability or the different lot sizes required.
To know the impact of complexity drivers is a crucial success factor for intelligent decision-making whereas it supports managers by revealing the causes for performance issues. Engineers knowing the interdependences and the effects of changing requirements can proactively consider it within decision-making in the design process. The knowledge about changing customer requirements lead to a fitting flexibility level in the product architecture or in the production design to be able to react to changing requirements faster and with lower cost. Thus it systematically supports decision-making for development, production as well as supply chain.

The following section 3 describes a new methodology how producing companies can systematically master the complexity of product or process designs through improving the performance of theirs decision-making.

3. Complexity Index (CI) methodology

This method is divided into five main steps (see figure 3). The starting point is the identification of complexity driver. A complexity driver is a crucial design element of the products and processes and increases the difficulty of decision-making. The second step contains the systematic analysis of the performance impact certain complexity drivers or driver groups have along the process chains. Within the third step the gathered information are transferred into an evaluation concept which represents the decision-making support model. In the fourth step the concept is finalized by building one complexity index. The methodology closes by integrating it into the design decision-making flow.

The goal of the methodology is to implement a systematic evaluation of different design solution alternatives to reduce the complexity or vice-versa to increase the intelligence of decision-making. The complexity index helps to improve decision-making performance meaning getting closer to the optimal solution.

### 3.1. Step 1: Complexity driver identification

The evaluation of certain designs is often based on subjective decision-making under an insufficient information basis which impact this decision could have on follow-up processes. To address this type of problem design groups need to clarify the understanding of the dependencies between their design and theirs related effects. Hence the first step of the method is to identify complexity drivers of the product design. Based on the complexity drivers communicated in research, the group of experts from different functional departments which are connected with the problem need to work out these drivers in a cross-functional workshop. Table 3 shows the results within the test design development.

| Complexity driver | Author |
|-------------------|--------|
| # of external components on PC and PIB | Novak & Eppinger (2001) [16] |
| # of standard deviations | Fixson (2005) [13] |
| # of different test temperatures | Martin & Ishii (1996) [7] |
| # of difficult testing parameters | Fernhaber et al. (2011) [17] |
| # of new hardware components | Bozarth et al. (2009) [18] |
| Parallelism level | Jacobs (2008) [15] |
| # of different lot sizes | Größler et al. (2006) [20] |

### 3.2. Step 2: Complexity driver analysis

In the second step the dependency knowledge as well as the sensitivity of the relationships of the system elements will be generated. This is done with the help of the pair-wise comparison methodology. It can be calculated with standard methods provided by Satty [21].
Within the interdependency analysis of the system elements weighting factors $w_i$ can be calculated for the complexity drivers with the arithmetic mean.

$$w_i = \frac{1}{n} \sum_{i \neq i} R_i R_n$$

After that the performance measures need to be defined, divided into overall objective and sub-criteria on lower hierarchy levels. Therefore experts, connected to the system design along the value chain of pre- and post-processes, should be included in the evaluation process. Within the assessment it is mandatory to include experts from different functional perspectives to ensure objectivity. In the case experts from product and test development, operations as well as procurement and finance have taken part in.

The performance impact assessment has to be conducted for the complexity drivers at their highest occurring value level. At the beginning this can be done with a qualitative evaluation systematic. Figure 5 illustrates the evaluation concept and the results within the case.

The major benefits coming out of the generated transparency is the disclosure of the impact certain drivers have, where target conflicts may occur and optimal levels can be achieved. Figure 6 shows the results of that qualitative evaluation for one driver. In this case it contains the impact results for the parallelism level driver.

It is obvious that a high parallelism level has a huge positive effect on the test time, but it comes along with a lot of disadvantages in procurement, development and operations due the complexity of the architecture. It is recommended to do a longitudinal data analysis to quantify the impact of the drivers and to achieve higher accuracy levels in the refinement of the evaluation.

The third step explains how to systematically transfer this generated and valuable information into an evaluation concept which can be used as a decision-making support.
3.3. Step 3: Evaluation concept

In the third step the evaluation concept need to be derived out of the generated knowledge. Therefore it is mandatory to define the evaluation steps for each kind of complexity drivers and for identified complexity driver groups.

First take a driver and classify it along the respective values into the complexity categories starting from one (simple) till five (very complex). Table 4 illustrates an example.

Table 4. Complexity driver characteristics and related CI-index-value.

| Driver value | CI-index-value |
|--------------|---------------|
| >25 (very high) | 5 (very complex) |
| 15-25 (high) | 4 |
| 6-15 (medium) | 3 |
| 2-6 (low) | 2 |
| 1-2 | 1 (simple) |

Second, take a performance measure and analyze the impact the driver has on it by changing the driver value. Keep the other drivers constant at first sight. Repeat that step for each driver value and performance measure till all characteristics are defined. Try to use mathematical functions to describe the relationship “drivers and performance measures” (e.g. linear, exponential, etc.). Figure 7 illustrates an exemplary result of a driver performance impact characteristic.

Fig. 7. Complexity driver performance impacts.

After having defined all evaluation steps and combinations, data need to be analyzed in order to quantify and to validate the defined complexity evaluation model. Refine and adapt the evaluation concept in steady time intervals.

At the end of this step all complexity driver are linked to complexity indices and respective performance values.

3.4. Step 4: Build the complexity index

In the fourth step the complexity index (CI) and the related performance impact value is calculated. The complexity index is the sum of the different CI-index values. The related performance impact values are computed with the arithmetic means along all performance measures. Table 5 shows an exemplary evaluation of a certain test solution characteristic.

Table 5. CI and performance impact values.

| Complexity driver | CI-index-value | Weighted performance impact value (Ø) |
|-------------------|---------------|---------------------------------------|
| # of external components on PC and PIB | 5 | -2.5 |
| # of standard deviations | 4 | -1.5 |
| # of different test temperatures | 5 | -2.5 |
| # of difficult testing parameters | 3 | -3.0 |
| # of new hardware components | 2 | -1.5 |
| Parallelism level | 5 | -3.5 |
| CI=24 | -2.4 |

The CI is a fast and first indication for the complexity which comes along with certain requirements and technical implementations. For further details it is recommended to go one step deeper the architecture hierarchy level to gain more insights about the performance impact characteristics.

Step 5 explains how the CI can be used within decision-making processes.

3.5. Step 5: Integration into decision-making process

The final step explains how to implement the CI logic into the decision-making process flow. Figure 8 shows an exemplary workflow within the decision-making process for the chosen case. In general the CI should be used as a decision-making support for the evaluation of different design alternatives.

Fig. 8. Decision-making process flow.
First the tool analyzes the requirements. Based on the requirements it matches the requirements with existing solutions. In the case it is a test solution catalog which has been implemented in an IT-tool. After this step different solutions will be presented and the computation of the complexity index for the different solutions will be conducted. After that step experts need to define and weight the goals to optimize for. Thus it does not mean that a low complexity index will automatically be the best “solution”. It has to be considered out of a broader perspective and in the context to the expected external constraints and set goals. Table 6 shows an exemplary result overview.

| Solution alternatives | CI-Value | Performance impact value | Goal fulfillment |
|-----------------------|----------|--------------------------|------------------|
| Solution 1            | 17 (medium) | -0.5                     | Very high        |
| Solution 2            | 22 (high)  | -2.4                     | High             |
| Solution 3            | 8 (low)   | 0.5                      | Medium           |

In this case the solution one is the closest solution to the set goals and due to lower complexity levels. Beside the solution for finding the optimal solution it helps to uncover hidden improvement potentials by having a better understanding of cause-effect relations. The complexity index is a support in handling complex information. It improves the planning for cross-functional collaboration activities. The subjectivity evaluation platform. This fosters a systematic increase of the complexity index to improve decision-making performance. Beside this improvement, a major side effect can be achieved by the complexity index. The index helps to break up the rigid boarders between the different involved functional departments by building a standardized basic evaluation platform. This fosters a systematic increase of the cross-functional collaboration activities. The subjectivity level within decision-making can be reduced and it supports to define goals which are optimal for the company and not only for a single functional department.

In the context of the outcomes and performance relations of complexity indicators more research efforts will be necessary to use complexity index models as multi criteria decision support systems. Therefore future research activities should focus on building up deeper understanding of the impact certain complexity drivers will have on specific performance indicators.

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