Kungliga Tekniska Högskolan

Development of a Complexity Management Model for Strategic Business Units

Department of Production Engineering and Management

In cooperation with Freudenberg Sealing Technologies GmbH & Co. KG

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Declaration

I hereby declare that I have developed and written the enclosed Master thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. The Master thesis was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

Stockholm, 2017-08-29

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Sascha Vollmer
Sammanfattning


Abstract

While there is an increasing number of influencing factors at the company, their complexity increases without counter-measures. To actively process the complexity on Lead Centre level at Freudenberg Sealing Technologies a management model to identify, measure, and evaluate the complexity is invented. Therefore the main external and internal complexity drivers are identified and evaluated. Tools and methods are connected to the drivers and their impact on the complexity is assessed. Finally a complexity index for the external, internal and entire complexity is invented to show statistically their
complexity score. The goal is to identify and process the complexity of a Lead Centre as a whole rather than the sum of its parts.
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<td>Complex Adaptive System</td>
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<tr>
<td>CC</td>
<td>Competence Centre</td>
</tr>
<tr>
<td>CI</td>
<td>Complexity Index</td>
</tr>
<tr>
<td>CI_e</td>
<td>External Complexity Index</td>
</tr>
<tr>
<td>CI_i</td>
<td>Internal Complexity Index</td>
</tr>
<tr>
<td>FST</td>
<td>Freudenberg Sealing Technologies GmbH &amp; Co. KG</td>
</tr>
<tr>
<td>Growtth</td>
<td>Get Rid Of Waste Through Team Harmony</td>
</tr>
<tr>
<td>LC</td>
<td>Lead Centre</td>
</tr>
<tr>
<td>Ops</td>
<td>Operations Manager</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SBU</td>
<td>Strategic Business Unit</td>
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<tr>
<td>SCM</td>
<td>Supply Chain Management</td>
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<td>SME</td>
<td>Subject Matter Expert</td>
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Introduction

1 Introduction

To simplify the introduction into the work, a short overview will be provided. Initially the introduction gives a short overview about the company as well as the current situation of complexity management including a description of the project and their occasion. The objectives are following and conclusive the structure of the thesis finishes the introduction part.

1.1 Project description

Freudenberg Sealing Technologies GmbH & Co. KG, hereafter named FST, is structured, as it can be seen in figure 1, regarding to their field of applicability (Division) which are Oil Seals Powertrain & Driveline, Oil Seals Damper & Steering, Oil Seals Industry, Special Sealing, Fluid Power, O-Rings, Gasket, Corteco, Accumulators, and Industrial Services. Each Division consists of one or more Global Lead Centre(s) which are considered as Strategic Business Units (SBUs). These Lead Centres are responsible for one product group regarding to global standards in Product Marketing, Material Development, and Engineering. To meet the customer requirements globally and locally, LCs can run subsidiaries for example Competence Centre (which focus on one region) or Partner Production (which act as an extended workbench) if required.
Due to LC differences in terms of market- and customer-related-factors, as well as location specific factors, the complexity of the company continues to grow. These differences makes it more difficult to quantify the complexity and to define targeted recommendations for the individual locations.

1.2 Project objectives

To handle complexity in the Lead Centres the influencing factors (complexity drivers) which describes the complexity will be investigated. Based on this investigation an evaluation method will be introduced to connect the complexity drivers with a weighting factor. With the result, a complexity index is calculated to determine the internal, external and entire complexity of the Lead Centres. Thereby

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1 Cf. FST internal source.
is the product portfolio as well as the capabilities of the sites and their integration into the FST production network taken into account. Finally recommendations for action are rendered with which the complexity can be reduced, controlled and prevented.

The objective of this Master Thesis is to implement a guideline with which the FST Lead Centres can process and reduce / eliminate both the internal and external complexity.

1.3 State of the art at FST
There are already several basic approaches to detect and evaluate complexity, whereby the literatures’ focus is either on the company in general (Voigt, Wildemann 2011) or very specified to one specific area (Kersten et al. 2012; Mayer 2007; Meyer, Brunner 2013; Serdarasan, Tanyas 2012). Also the focus at FST is much specified therefore the few sporadic approaches and projects in complexity management are separated in different organizational departments (e.g. Production, Lean / Growth, and Supply Chain Management).

These projects were realized both, company internal and in cooperation with external research institutes like the Fraunhofer Additive Manufacturing Alliance. The complexity process concept which was introduced together with Fraunhofer is called “Segmentation” and is applicable in the Production area. The target hereby is to cluster product segments with similar properties like value chain, materials, markets and production volume to optimize them internal with Lean methods (Bauernhansl 2014, p.36). Another
internal project dealt with the optimization of the Supply Chain based on complexity driver research.

The limitation with these projects was that the focus of the complexity, and therefore the complexity drivers, were only internal. External complexity has not been taken into consideration.

To widen the range of applicability and to introduce a companywide standard to process the internal and external complexity in coherence with their structure, FST launches an active complexity management on Lead Centre level. The objective is to develop a possibility with which the LCs, including their different structure relating to technology, market, environment, customer, processes, value creation, products, organization and logistics can be compared.

1.4 Thesis structure
The structure of the thesis, as it can be seen in figure 2, includes 5 major steps which again are divided into smaller parts.
Figure 2: Structure of the thesis.²

To get a better overview of the approach of the thesis, the first step is the introduction where the background, the state of the art and the objectives are listed. Then the theory part follows to clarify the wording and to provide the background information of the topic. Afterwards the used methods are described including their outcome. The objectives of the thesis are shown in chapter four and to top the work off, a summary is provided in chapter five as well as an outlook to the future work.

² Cf. own illustration.
2 Theory

The first step in the editing of the topic is to deal with the concepts around the subject of complexity management. This includes the explanation of complexity, their relation to the Strategic Business Units (Lead Centres) and the management. Furthermore, complexity drivers are expounded as well as the idea of the complexity index and the management processing tools.

2.1 Complexity

To develop a complexity management model at first it must be clarified what is understood by “Complexity”. Because there are different framework parameters and perspectives for a company an universally valid definition does either not exist or is not applicable in this situation (Bandte 2007). Depending on the context of applicability the definition and meaning of complexity differs.

Westphal affiliates the complexity of a company to the three factors complicacy, dynamic and non-security (Westphal 2000, p.19). Furthermore he stated complexity in the view of a production system and reached the awareness that the complexity is the problem of producing a certain production program in the right quantity, quality and time.

Besides the dynamic both Zielowski and Bauernhansl believe that variety and transparency are parts of the complexity (Zielowski 2006, p.28; Bauernhansl 2014, p.37). Transparency, or non-transparency, is
also mentioned by Ehrlenspiel who entitles the quantity of variables, connectivity and momentum as parameters belonging to the complexity of objects (Ehrlenspiel, Meerkamm 2013, p.167). Another approach to specify complexity through the attributes of a system is to divide them into several aspects like numerical, relational, variational, disciplinary and organizational complexity. By specifying the attributes instead of specific factors, there is more space for interpretations and simultaneously more complexity factors are covered. Additionally the numbers of disciplines involved are named.

A more general description is provided by Buhr and Klaus (Klaus, Buhr 1979-1980). They define the complexity of a system through the properties determined by the number of elements of the system and the relations between them. The degree of complexity increases regarding the number of the elements as well as the relation between them.

Instead of trying to define complexity through the components of a system, Dekker (Dekker et al. 2011) defines complexity as a characteristic of a system and goes the same way as the Gabler Wirtschaftslexikon (Gabler dictionary of economics) which defines complexity as it “is understood as the variety of the behavioural possibilities of the elements and the variability of the course of action”.

Whereas the other explanations tend to provide specific factors is the explanation of Gabler to understand the overall term “Complexity” independent of the field of application.

While Piller describes the complexity of a system with the upcoming complexity costs does Marti differentiate between internal complexity and external complexity to be able to identify and process complexity on a company level (Piller, Waringer 1999, p.130; Marti 2007, p.25).

As it can be seen there are a number of different explanations for complexity which partly includes the same elements. The mostly named elements of the complexity are the dynamic, the transparency, the variety, and the complicacy.

Based on the number and diversity of explanations and definitions, complexity cannot be described by one clear definition but perhaps a clear definition is not necessarily intended. According to Fellermann topic related definitions would lead to avoid misunderstandings with other sciences (Matthies 2003, p.26).

2.1.1 Complexity vs. Complicacy

To prevent misunderstandings when using the term “Complexity” the difference between complexity and complicacy is expounded. Even complexity is often implied with complicacy it has neither the same meaning nor identical entities.

Components and systems can be complicated but that does not necessarily mean that they are complex. It is rather that complicacy is
a subarea of complexity (Bauernhansl 2014, p.37). When a situation has a high variety and heterogeneity it is complicated but without being dynamic and non-transparent it is not complex (Kluth et al. 2014a). As long as a system is understandable and describable in principle it can be complicated indeed but hence it is not complex (Dekker et al. 2011).

A complicated situation consists of causal interrelationships between corresponding objects (Kluth et al. 2014a), it can be not simple but knowable and controllable (ElMaraghy et al. 2012). Otherwise a complex situation is neither knowable nor controllable because of uncertainty exists (ElMaraghy et al. 2012) and non-causal but surprising interrelationships (Kluth et al. 2014a).

2.1.2 **External Complexity**

Although there is no standardized definition of complexity, there is a distinction between external complexity and internal complexity of an organization (Marti 2007). The external complexity can be described as complexity which is located outside of the organization but influences the company’s behaviour direct or indirect. This means that the origin of the company’s complexity can be external but the treatment has to be done internal. Thus the organization’s value-chain is strongly dependent and influenced by the external complexity (Marti 2007).

Therefore the external complexity is influenced particularly by the market which includes, besides the common fluctuations also global
events (e.g. catastrophes, country specific requirements, population growth, etc.) and changes in technology (e.g. digitalization or Industry 4.0). Their characterization can be indicated by the changeability and flexibility (Kluth et al. 2014a) which is measured by the amount of input, information, and energy obtained from the environment (Jost 2004).

2.1.3 Internal Complexity

The counterpart to the external complexity is the internal complexity which can be indicated as the company’s perspective on complexity. The internal complexity measures the input by the system (Jost 2004) and can be characterized by the occurrence and fields of the complexity dimensions (Kluth et al. 2014a).

Internal complexity in consequence of the translation of external complexity is influencable directly and hence cannot be considered isolated (Kluth et al. 2014a; Marti 2007).

Internal complexity is often higher than external due to a transformation of external complexity into internal. To adjust the internal and external complexity, two main strategies exist. One is to reduce the internal complexity to make a controllability of the external complexity possible (Grochla 1980) and the other is to equally both types of complexity (Ashby 1956; Bauernhansl; Kluth et al. 2014a).
The balancing of both complexities has different approaches. Ashby (Ashby 1956) indicates that market potentials only can be used when the internal and the external complexity are on the same level while Kluth (Kluth et al. 2014a) and Bauernhansl (Bauernhansl 2014) name the processability of the external complexity as the main reason. According to them the external complexity can only be processed effective when there is an equally strong internal complexity. Otherwise the process effort is either very high or there must be done unnecessary tasks which leads to an inefficient company (Bauernhansl 2014, p.37). Equilibrium of the complexity is intended because of their connectedness and interdependency.

2.1.4 Good and Bad Complexity
Although complexity is mostly implied with something bad which has to be reduced and avoided there is also good complexity.

At least a certain level of complexity is necessary to meet the customer needs. For example there must be a number of product variants (internal complexity) to deliver several customers together with globalization (external complexity) to be present on markets worldwide. If the complexity is reduced under a certain level the customer needs cannot be fulfilled anymore (Kersten et al. 2012).

The questions companies have to ask themselves about the level of complexity is what is intended, what is avoided, and what is necessary and then weight them to find the optimum combination.
Thus the objective should be to eliminate complexity that the customer is not willing to pay for.

2.2 Complexity in Strategic Business Units

While a traditional structured organization is oriented on core- and support processes (Schober 2002), the Strategic Business Units (SBUs) structure is object (product) oriented, which allows a quicker response to changing economic and market situations (Ringlstetter 1997). This means that the scope of SBUs consists of several business organizations like Production, Marketing, Logistics / SCM, Purchasing, R&D, Quality, and Sales which have to be taken into consideration simultaneously whereas the process-orientation can focus on one organization after the other.

Since there are a number of organizations interacting internally and externally the Strategic Business Unit, there are more possibilities which influence the complexity. Thus, both the internal and external complexity is significantly higher than in only one individual department.

Because the SBUs consists a large number of components that interact and learn from each other, they can be declared as Complex Adaptive Systems (CAS). A CAS is a developed form of a Complex System in where the components (business areas) specializes, adapts and reproduces themselves according to changes in their environment.
2.3 Complexity Drivers

When talking about complexity in general and in SBUs the term complexity driver must appear. Although there are, same as the definition of complexity, no coherent definitions or descriptions of complexity drivers.

However, the literature defines complexity drivers as factors which affect the level of complexity of organizations and value chains. Meyer (Meyer et al. 2007) and Piller (Piller, Waringer 1999) clarifies the complexity drivers as a phenomenon which increases the own complexity whereas Krizanits (Krizanits 2015) states that new functional models can occur due to turbulences caused by drivers.

However, complexity drivers are factors which influence the complexity in a company and can be divided into external complexity drivers and internal complexity drivers. The differentiation is based according to their origin whereas an accurate differentiation is not always possible. Contrary Vogel (Vogel, Lasch 2016) defines complexity drivers as factors which leads to a change in a system’s complexity level which can either be positive or negative.

The ignorance Vogels about the positive or negative changeability of the complexity can be attributable to the connectivity between internal and external complexity drivers, which is strongly distinctive. Therefore it is not always possible to decide if the complexity is reduced or increased when some complexity drivers are adjusted (Adam 2001, p.10f). However, they must be known otherwise an
effective complexity management cannot be developed (Serdarasan, Tanyas 2012; Heydari, Dalili 2012).

2.3.1 External Complexity Drivers
An external complexity driver is located outside the organization and has direct influence of the organizations complexity. Their origin is market-based and represents the market requirements (Piller, Waringer 1999; Schubert 2008). Besides the market-based complexity (demand-, competitive-, supply-, technological-, and general market related-complexity), which contains mostly hard-factors, there is also the society-based complexity (cultural-, ecological-, legal-, political- factors, standards and regulations) which contains soft-factors. The separation of the external complexity drivers is, as shown in table 1, based according to their commonalities.

The main characteristic quality is that they are not, or nearly not directly influencable by the organization itself because they are not induced by the company (Binckebanck et al. 2013). This does not mean that they cannot process at all however, the treatment, if possible, occurs in a more indirect way.

<table>
<thead>
<tr>
<th>Society Complexity</th>
<th>Market Complexity</th>
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<tr>
<td>o Cultural factors</td>
<td>o Demand complexity</td>
</tr>
<tr>
<td>o Ecological factors</td>
<td>o Competitive complexity</td>
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When processing external complexity drivers companies tend to transfer them into internal complexity drivers. That implies that internal complexity is build up by an unwanted increase and accordingly non-value-adding complexity (Vogel, Lasch 2016) whereby the external complexity decrease.

2.3.2 Internal Complexity Drivers

An internal complexity driver is located inside the organization and has direct influence on the organizations complexity. In contradiction to external drivers they can active and directly be influenced by the organization (Aelker et al. 2013).

The classification of the internal complexity drivers is bipartite, too. The classification ensued, as it can be seen in table 2, into internal correlated (target-, customer-, product and product portfolio-, technological-, product development-, supply process-, service-, and remanufacturing-complexity) and internal autonomous (organizational-, process-, planning-, control and informational-,

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3 Cf. own table based on Vogel 2016, p.28.
production-, resource-, logistics-, sales and distribution-complexity) complexity drivers. Correlated drivers are related to the market which means that they cannot be considered independently whereby autonomous drivers are at least partly independent from the market.

<table>
<thead>
<tr>
<th>Internal Correlated</th>
<th>Internal Autonomous</th>
</tr>
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<tbody>
<tr>
<td>o Target complexity</td>
<td>o Organizational complexity</td>
</tr>
<tr>
<td>o Customer complexity</td>
<td>o Process complexity</td>
</tr>
<tr>
<td>o Product and product portfolio complexity</td>
<td>o Planning, control and information complexity</td>
</tr>
<tr>
<td>o Technological complexity</td>
<td>o Production complexity</td>
</tr>
<tr>
<td>o Product development complexity</td>
<td>o Resource complexity</td>
</tr>
<tr>
<td>o Supply process complexity</td>
<td>o Logistics complexity</td>
</tr>
<tr>
<td>o Service complexity</td>
<td>o Sales and distribution complexity</td>
</tr>
<tr>
<td>o Remanufacturing complexity</td>
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</table>

Table 2: Internal Complexity Driver’s Classification System.\(^4\)

Their origin is resource-based but can be distinct whereas it occurs either as a result of external complexity or induced by the company itself (Vogel, Lasch 2016). Even an influencing factor is declared as

\(^4\) Cf. own table based on Vogel 2016, p.28f.
an internal complexity driver, their origin can be external. This transformation from external drivers to internal leads to a disproportional surge of the internal complexity.

2.4 Complexity Management

For an organization it is important to be competitive by acting and reacting on existing complexity. To achieve the competitiveness, the complexity management can be seen as a strategic issue for the organization (Vogel, Lasch 2016). By improving the company’s competitiveness, and therefore their success, the internal and external complexity drivers are the main adjusting levers.

When complexity management is named, several authors refer it with variant management and their reduction (Lindemann et al. 2009). However, the objective is not to reduce the variety or the overall complexity as far as possible but to find an optimum level of complexity (Marti 2007).

However, before complexity can be managed it has to be identified, and measurable indicators must be introduced (Bauernhansl 2014, p.38). Furthermore complexity must be made transparent. Without knowing the internal, external and overall complexity peculiarity of the organization, possible methods or tools are useless because their applicability and impact is unknown.

When it comes to the approach of complexity there are, according to the results of a study (Studie Komplexitätsbewirtschaftung) taken by
Jäger in 2014, three main groups of participants regarding the complexity management in companies can be subdivided (Jäger et al. 2014):

1. Challengers
2. Followers
3. Ignorants.

Challengers are aware of the relevance and importance of complexity in organizations and the need to process it. Furthermore they started with introducing a complexity management and they already have tools and methods in use.

Followers are also aware of the complexity management in general although, they have neither tools nor methods in use yet.

Ignorants had not had a critical look at complexity at all.

However, 99% of the participants believe that the importance of complexity in companies will either increase or at least stay as important as it is. This shows the necessity and importance of an active and successful complexity management.

2.4.1 Strategies for Complexity Management
To introduce and process a successful complexity management there already exist several attempts. As a strategy a structured, long-term related approach to handle and manage the internal and external complexity of an organization is meant.
For complexity management two main strategies can be followed: Complexity manipulation and accomplishment of complexity (Jäger et al. 2014). On that account Jäger defined five approaches to follow these strategies:

- **Avoiding Complexity**: A proactive instrument to avoid over-complexity by introducing standardization methods in products, processes and organizational structure.

- **Reducing Complexity**: A re-active instrument to reduce the existing, non-value-adding complexity and find an optimum level.

- **Generating Complexity**: An instrument to increase the internal complexity. This method is used when the internal complexity is too low and the competitiveness is not ensured.

- **Dealing with Complexity**: Aiming the efficient coping with unavoidable internal complexity.

- **Pricing Complexity**: Pricing of products as long as customer is willing to pay for it. This method is sometimes difficult to implement because of the high customer dependency.

Lindemann (Lindemann et al. 2009) follows the bipartite theory of complexity avoidance and reduction, as well as complexity management and control. The theories partly overlap with those of Kluth, though. Nevertheless, Lindemann is convinced that a complexity management strategy will only lead to success when the complexity system is captured and evaluated (Lindemann et al. 2009).
For the acquisition and evaluation of complex systems analytical methods, basic structural subsets, index values related to fundamental structural characteristics, structure evaluation and case specific analyses are used. However, to capture and evaluate the system is highly time-consuming and comprehensive.

Wildemann and Bauernhansl divided complexity management into three strategies which are the reduction of complexity, the control of complexity, and the prevention of complexity (Voigt, Wildemann 2011; Bauernhansl) whereby Bauernhansl additionally names complexity enhancement if required.

Although complexity management does not start with one strategy and ends with another it is more an ongoing process which can be started with each of the three strategies.

As it can be seen, the three strategies “Reduction”, “Control”, and “Prevention” are used by all authors. Also the application and intention is similar even there are slight differences, though. Even though it might be expected that prevention and avoidance of complexity is the objective of every organization, it is not. Rather the level and balance of complexity leads to the controllability of the internal and external complexity and the final strategy still depends on the specific company’s situation.

Nevertheless, the strategy for complexity management is also correlated to the organizations level of complexity management.
Depending on which complexity management level the organization is, a different approach will be chosen and another strategy is followed.

### 2.4.2 Level of Complexity Management

To know the own level of complexity management is essential before the evaluation can start. According to Kluth (Kluth et al. 2014b, p.72f) there are seven different levels of complexity management, as shown in table 3, which differs in terms of capturing complexity and process complexity.

<table>
<thead>
<tr>
<th>Level-number</th>
<th>Level name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Initial</td>
<td>The company has not yet concerned or recognized any complexity problem or strategy.</td>
</tr>
<tr>
<td>1</td>
<td>Defined</td>
<td>The company has identified external complexity drivers and has defined internal complexity fields.</td>
</tr>
<tr>
<td>2</td>
<td>Qualitative</td>
<td>The company uses methods to evaluate qualitatively existing complexity within the specific complexity fields.</td>
</tr>
<tr>
<td>3</td>
<td>Quantitative</td>
<td>The company has elaborated specified Key Performance Indicators (KPI), in order to quantify the existing complexity in terms of the four complexity dimensions.</td>
</tr>
<tr>
<td>4</td>
<td>Analysed</td>
<td>The company has analysed the existing internal complexity and generated so-called complexity</td>
</tr>
</tbody>
</table>
patterns by detailed analysis of the complexity fields and dimensions based on the correlation of specific, selected indicators.

| 5  | Managed          | The company has defined and initialized specific complexity cultivation strategies in order to adapt or master the existing internal complexity. |
| 6  | Harmonized       | The company has optimized its internal complexity according to the external complexity on the market and the company is able to dynamically adapt and adjust it permanently. |

**Table 3: Levels of Complexity Management.**

The level of complexity management is an indicator for organizations to evaluate their existing understanding and management of complexity. Furthermore, by being aware of the own complexity knowledge, actions can be figured out to improve the own complexity management to reach the next level. The advantage of categorize the complexity into different levels is, that it makes it easier to identify the next steps to improve the complexity management. On the other side there is the risk of just trying to be in a certain level without taking the required actions seriously.

As it can be seen in table 3 the level of complexity management increases first by handling the external and afterwards the internal

---

5 Cf. own table based on Kluth 2014.
complexity. The approach for both fields of complexity is the same and the path from level 0 till 6 is based on each other. This means that without fulfilling all previous levels, the next one cannot be reached.

In general it can be said that the level of complexity management is dependent on the degree of centralization, as it is done by Bauernhansl (Bauernhansl 2014, p.36). The lower the level of complexity management the higher is the degree of decentralization and autonomy. Again, here it is not the target to reduce complexity as far as possible but to find the optimum level of internal and external complexity for the own organization.

### 2.5 Complexity Index

To identify, the internal and external as well as the entire complexity of an organization, a complexity index is used based on the identified complexity drivers. According to the business dictionary an index is a statistical device which summarizes a collection of data in a single (Business Dictionary) base figure. Therefore the index consists of both the complexity drivers and their emphasis.

The target is to explain the complexity of the Lead Centres as a whole rather than the sum of its parts. Due to the calculation of the weighted impact of the complexity drivers on the LC this goal is reached. By summarizing the LCs complexity in an index it is more descriptive than observe the individual assessments. Based on the internal and external complexity index the cause of high complexity which has to
be processed can be found out. Furthermore it is the basis to compare the own organization over time and with other organisations.

With the index the complexity is depict which simplifies their treatment. Therefore the methods which are recommended are dependent on the result of the complexity index investigation. After the actions have been taken, their impact can be seen by evaluating the complexity index again.

However, the complexity index can be used to compare the own organization with similar organizations. A precise comparison can only be given when the structure and the circumstances are identical which is rarely the instance.
3  Method

The subsequent chapter contains a description of the used methods and their impact on the project. Furthermore, the way how they are used as well as their impact on the results are included.

3.1 Method Description

To be covered below the used methods as well as their impact and results are described. The methods are structured as shown in figure 3.

1. Acquisition of the complexity drivers from the literature
2. Development of a driver catalog
3. Crossover of the drivers in an Ishikawa diagram
4. Investigation of missing and overall reduction of drivers
5. Determination of the impact of the complexity drivers
6. Investigation of methods to process the complexity
7. Correlation of the tools with the complexity drivers
8. Development of a complexity index
9. Determination of the complexity index for FST LC
10. Derivation of recommendations for action
Since the term of complexity was extensively described the acquisition of the complexity drivers is the first step. After the drivers are collected out of the literature the development of a driver catalogue, to cluster and structure the drivers, follows. As a preparation for the reduction of them, they are transferred in an Ishikawa diagram according to their characteristics. Based on the Ishikawa diagram redundant drivers are sorted out and missing drivers are added to complete and finish the collection of complexity drivers.

Subsequently the impact of the complexity drivers is determined whereupon they are quantified to find out their level of impact. To manage the impact of the complexity drivers, methods for the optimization of complexity are investigated and correlated with them.

After the level of impact of the complexity drivers are determined and the drivers are correlated to the management tools, the preconditions for a complexity index are fulfilled and therefore the complexity index is developed. With the developed complexity index the complexity for the Lead Centre at FST is determined. After the results of the complexity index are analysed, derivations of recommendations for actions are taken according to their level of optimization of the complexity index.

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6 Cf. own illustration.
3.2 Acquisition of Complexity Drivers from the literature

Complexity drivers are the basis for the whole progress of complexity management. With them it is possible to find the cause of high or low internal and external complexity. Furthermore, they are essential to develop a complexity index with which the different LCs can be compared and based on them recommendations for action to decrease complexity are derivated.

To identify the complexity drivers for FST a literature research was done. According to Vogel (Vogel, Lasch 2016), 281 complexity drivers on specific issues like logistics, supply chain and general in manufacturing technologies were identified by previous research studies done mainly by Meyer, Serdarasan, as well as Voigt and Wildemann. Furthermore, there are other complexity drivers which cover the other parts of a company such as marketing & sales, purchase & procurement as well as the overall value chain.

Even there are 281 complexity drivers not all of them are relevant for the project therefore, after a first selection, 157 complexity drivers (59 external and 98 internal) were left. During the first selection, complexity drivers which are obviously not relevant for the project, while not applicable or to abstract, or which are named several times in a very similar way are removed. To get these drivers articles, books, scientific papers and PhD theses were evaluated.
Method

Once the drivers were acquainted, they are divided into internal and external complexity drivers.

3.3 Development of a Driver catalogue

To receive a better overview of the complexity drivers from the literature a driver catalogue is developed. By using a driver catalogue the complexity drivers can be differentiated between internal and external complexity drivers and additionally clustered into different classes.

The differentiation into internal and external complexity drivers was done in coherence with the development of a driver catalogue. Within the catalogue the complexity drivers are clustered into 5 external (Technology, Market / Competition, Customer, Environment and Other) and 6 internal (Processes, Value Creation, Products / Development, Organization, Logistics and Other) classes. The election of the classes ensued based on Voigt and Wildemann (Voigt, Wildemann 2011) and the final assignment was carried out due to the characteristics of the drivers.

Although the driver catalogue is reminiscent to those of Voigt and Wildemann, there are differences in the selection and naming of the classes as well as in the allocation of the driver to the classes. The differences appeared by including more complexity drivers from other sources whereby the template is not applicable anymore. Furthermore, the allocation is specified to FST which leads to a different interpretation and application of drivers.
After the differentiation was completed, the drivers were assigned according to their properties which means, the drivers which influences similar departments, organizational units or processes are clustered together in one class. Here the focus is to cluster as many drivers as possible into only a few classes to find similarities and possible overlapping at the drivers which simplifies their reduction.

Without clustering the drivers a sharp differentiation as well as a meaningful selection of the relevant drivers would not be possible. After the separation and classification redundant multiple answers as well as similarly declared drivers have been removed to avoid redundancies.

3.4 Ishikawa diagram
To enable a clearer allocation and subsequent evaluation of the ascertained and pre-selected complexity drivers, the classified drivers are transferred in their respective categories in an Ishikawa-diagram. The also as Cause-and-Effect Diagram described method is used to simplify the search for the cause of the problems. In case of the complexity drivers it is used to figure out which driver effects which category.

The transformation in the Ishikawa diagram was done for both the internal and the external complexity driver with the target to get by two levels – the categories on the first level and the drivers on the second. The built categories represent the segments which the drivers
affect the most. To avoid multiple responses, drivers which effect more categories are only allocated once.

Based on Ishikawa the evaluation of the important drivers was done. Therefore each driver was critically evaluated to figure out if it is relevant for the Lead centre comparison or not.

The evaluation is done regarding to the Pareto-Principle (also known as 80 / 20 rule) which indicates that 80% of the results are achieved with 20% of the total expenditure (Sanders 1987). The remaining 20% of the results require 80% of the work. For the complexity management this means that 80% of the complexity is caused by 20% of the complexity drivers. Therefore the number of the internal and external complexity drivers is respectively reduced by approximately 80%.

Furthermore, for the evaluation are the hypotheses by Voigt and Wildemann considered as well as the practice-relevance of the driver. This means, that the drivers which are related to the rejected hypotheses are also not taken into consideration anymore.

3.5 Investigation of missing and overall reduction of drivers
To investigate possible relevant complexity drivers which are not included in the literature a company internal survey is taken. The survey not only tend to investigate missing complexity drivers but
Method

also to get an overview about the companywide known and used complexity processing tools and methods and what their strategy is.

Before the survey was sent to the participant it was tested with several employees from the department Lean / Growth / SCM to check the understandability and the feasibility of the survey. According to the feedback of the test participants the survey was optimized and sent out to 176 candidates from six divisions (Sales, Marketing, Operations Manager, Engineering, Lead Centre / Competence Centre Manager, Lean / Growth / SCM). The divisions are chosen to make the survey representative. The selection of the number of candidates per department and the candidates itself was done regarding to the organizational structure of FST and the corresponding positions.

To give the participants enough time to answer the survey and to get enough feedback for the evaluation a timeframe of two weeks is provided. Answers which return afterwards are not taken into consideration.

The survey is tripartite and consists 12 questions in total whereas the first part is to inquire general information about the survey candidate. The second part is about internal and external complexity drivers. The focus here is to evaluate the pre-selected drivers regarding their relevance and importance as well as to add drivers which are, in the opinion of the participant, influencing the complexity. The third part is to evaluate the complexity processing tools and methods in use.
Because the focus of this project is on Lead Centre levels, complexity drivers which are either not applicable or which are equally at every Lead Centre, are not considered.

In the first section information about the survey participants are ascertained through the questions 1-5. Here the participant provides information about the segment he / she is working in, the production volume, the customer structure, the department belonging to and finally the fact if an active complexity management process is driven yet. By ascertain this information a correlation between the general information and the ranked and named complexity drivers is examined.

The second section „Complexity Drivers“ appears twice because it is used for both the internal and external drivers (therefore the questions have two numerations: Question 6 / 8 for the external and Question 7 / 9 for the internal drivers) equally. In the survey first the external and then the internal complexity drivers are prompted. The questions are identical but the pre-selected drivers are adjusted. The pre-selection is based on the Ishikawa ranking as well as the test runs with the Lean / Growthh / SCM department and several internal experts.

In the survey the participants are encouraged to rank the complexity drivers regarding their importance for the company. The rank consists of five steps from one to five where one represents the lowest importance and five the highest. If the participant thinks the driver does not have any influence or their importance is unknown there is
also the possibility to mark those with “Not specified”. Furthermore there is the possibility to name up to six additional complexity drivers which are, in the view of the participants, important but which does not appear in the pre-selection. To simplify the naming of additional complexity drivers, the Ishikawa-diagram is attached on the survey invitation.

The third section “Complexity Process Tools / Methods” is constructed to find and evaluate the tools and methods which are known and used FST internal. The section is specified to meet the different company areas, this means that dependent on the department selection the participant made in Question 4, different adjusted tools and methods appear. As an example when the candidate selects “Engineering” only tools connected to the engineering area indicates. The same goes with Sales, Marketing, Operations manager, LC / CC manager and Lean / Growth / SCM.

Here the candidates have to assign the tools which are either planned for usage, already used sporadic or which are in use consistently. Tools which are currently not used or which are not known can be marked with “Not specified”. There is also the possibility in question 11 to name up to six other methods and tools which are in use but not mentioned yet.

In the last question the candidates shall allocate the complexity processing tools according their strategy. This means that, as far as it is known, the tool is either used for complexity reduction, complexity
control or complexity prevention. At this point there is also the opportunity to mark unknown or not used tools with “Not specified”.

The investigation of missing drivers and methods / tools goes with the survey. While taking the survey, missing drivers will be figured out while an assessment is taken. Based on the classification of the drivers by the participants regarding their importance a first indication for the quantification is given.

### 3.6 Determination of the impact of the complexity drivers

Because every driver has to be ranked according to their impact on the Lead Centre the number of complexity drivers must not be too high. Otherwise the ranking might not be done with the necessarily accuracy and precision. Furthermore, the differentiation between different drivers from the same category is not always clear which leads to misunderstandings and to inaccuracies when calculating the index. To avoid misunderstandings, a short description of the driver is provided.

To determine the weighted impact of each driver a percentage for each individual internal and external driver is calculated. While having 18 internal complexity driver each would be weighted with \( \frac{1}{18} \times 100 \) (approximately 5.56%). For the external complexity driver the weighting would be \( \frac{1}{14} \times 100 \) due to the 14 drivers evaluated. This leads to a consistent balance of approximately 7.14% per driver.
The quantification is based on the evaluation of the driver done by the survey participants. Because each participant had to evaluate each driver regarding their importance and impact for the organization, a final score can be calculated and a ranking created.

Furthermore, to lower the subjectivity of the drivers when it comes to their evaluation for the complexity index, for each driver an evaluation method is established. However, it will not be possible to evaluate each driver objectively at least the subjectivity is decreased as far as possible by providing a detailed description of the driver. The reason here is to ensure a comparable environment when it comes to the comparison of the Lead Centres.

3.7 Complexity Process Tools and Methods
To process the complexity of the LCs there are a number of tools and methods which are already in use and which decrease, control or prevent the complexity whereas an accurate allocation to one of the strategies is not always possible. A pre-selection of the tools and methods which are already in use are filtered out of the FST intranet.

To ensure there right applicability, they are examined regarding their strategy and usage frequency. Since there are additional methods which exist but which are either not mentioned in the intranet or their utilization is unknown, these methods are evaluated with the same properties as the one from the intranet, too.
The selected methods are then clustered into three categories regarding the business unit they are relevant for: Operative, Administrative and Organizational. The category Operative contains the target groups “Operations Manager”, “Engineering”, and “Lean / Production / SCM”. In total there are 34 tools and methods which are applicable by this group. The Administrative category, with the “Marketing” and “Sales” departments, encompassed 24 methods and the “LC- and CC-Manager”, which are clustered in the category Organizational, comprised 44 tools and methods. However, the tools from the categories Operative and Organizational partly overlap.

For a better overview and understanding of the methods further information like a short description, their applicability, possible preconditions, the time frame for implementation, and the responsibility person (e.g. Subject Matter Expert) and / or department are provided. Additionally there is an URL-link which leads to more details about the method attached. Ancillary further information like costs for the implementation number of resources required or involved departments can be included. With this information, the applicability by each person, even if he / she is not familiar with the method, shall be ensured.

3.8 Correlation of the Tools with the Complexity Drivers
For a successful complexity management the impact of the complexity drivers has to be reduced by using different complexity process tools and methods. As described in the previous chapter there
are many methods which can be used. To ensure that there is the expected impact on the complexity driver there must be a connection between them.

Here it is important that every driver is connected to at least one method and the other way round. If the method does not have any connection to the drivers it is not relevant for the complexity process and can therefore be eliminated of the tool box.

The correlation process is done with experts from the five most affected departments: Lean / Growth, Purchase and Procurement, Corporate Function, Supply Chain Management and Marketing and Sales. The experts are asked to assign each method in three categories to the corresponding complexity driver. The categories are:

1. Low impact: There is a slight impact of the method to reduce the complexity driver.
3. High impact: The method strongly impacts the complexity driver

The differentiation in the three categories simplifies the evaluation-based recommendations for action to reduce the complexity. With the connection of the drivers with the methods a relevant recommendation can be provided with which the complexity at the LCs can be processed.
3.9 Development of a Complexity Index

To detect the complexity of the LCs, based on the individual assessment of the complexity drivers via the survey, a Complexity Index (CI) is launched. With the calculation of this index the internal, external and entire level of complexity is determined. The index is represented as an individual number for the internal complexity index \( CI_i \) as well as for the external complexity index \( CI_e \).

By using the adjusted weightings of the drivers instead of the equal weighting it is ensured that the as more important evaluated driver are also weighted more than the as less important evaluated driver. This leads to a more accurate determination of the complexity and therefore to a more precise interpretation of the results.

The formula for the calculation of the internal complexity index \( CI_i \), which is an indicator for the level of the internal complexity is as following:

\[
CI_i = \sum_{i=1}^{18} (\text{Internal Complexity Driver}_i \times \text{Evaluation}_i)
\]

The formula for the calculation of the external complexity index \( CI_e \), which is an indicator for the level of the external complexity is as following:

\[
CI_e = \sum_{i=1}^{15} (\text{External Complexity Driver}_i \times \text{Evaluation}_i)
\]
When calculating the internal and external complexity index, the resulting number has a range from 1 to 5 whereas 1 is the lowest achievable complexity and 5 the highest.

The overall complexity of the LC is calculated as the quotient of the internal and the external complexity index. The formula for the complexity index $CI$ is the following:

$$Complexity \ Index = \left( \frac{External \ Complexity \ Index_e}{Internal \ Complexity \ Index_i} \right)$$

Here the range goes from $2 \ (1/5)$ to 5 whereas 0.2 is the lowest achievable complexity index and 5 the highest. The range can be divided into three parts:

1. When the external complexity is higher than the internal complexity, then the index is between 1 and 5.
2. When the external complexity and the internal complexity are equal, then the index is exactly 1.
3. When the external complexity is lower than the internal complexity, then the index is between 0.2 and 1.

As an outcome, besides the calculated index, the amplitude of each driver appears. Based on the index and the evaluation of the individual complexity drivers, recommendations for action are provided regarding their amplitude and the level of evaluation of the complexity drivers.
3.10 Determination of the Complexity Index for FST LC

The determination of the complexity index for Lead Centres is done by developing a survey which the LC-Manager have to answer. A survey is chosen to ensure the consistency of determination and evaluation of the complexity. Therefore and because it is only applicable for LC-level, the survey is only done by the LC-manager without the candidates from other.

The survey is bipartite and consists of ten questions in total whereas the first section is to collect general information about the Lead Centre. The information is gathered to make them comparable among themselves and to see their complexity progress over time. To gather comparable information the number of employees as well as the turnover is asked. Furthermore, the development of some operation figures like the market share, the EBIT (Earnings before Interest and Taxes), or the ROI (Return on Investment) are prompted. With these questions the development and correlation of the LCs complexity can be determined. Furthermore, LCs with similar operation figures can be compared to find out if their complexity differs and why it is so.

Besides the operation figures the production volume is taken into consideration as well as the order fulfilment process. In comparison to the first survey the production volume is now further specified to avoid misunderstandings and misinterpretations.
In the second section, the determined and selected complexity driver which resulted from the first survey are evaluated according to their actual status at the Lead Centre. In comparison to the first survey not their general influence of the complexity is evaluated but the complexity status at the moment. The assessment range goes again from one to five where one is the lowest complexity and five is the highest. To make the assessment as objective as possible a more detailed description of the driver as well as an evaluation range is, where it is possible, provided.

Based on the evaluation of the complexity drivers the external, internal and entire complexity index is calculated as it is described in the previous chapter. Furthermore, tools and methods are presented with which the complexity can be processed.

The determination of the complexity index for the LCs will be done on one lead centre for test purpose. The result of the index determination is analysed afterwards to see if it coincidences with their status (by status KPIs like the profitability, efficiency, effectiveness, etc. is meant).

### 3.11 Guidance for action

Based on the results of the second survey for the determination of the LCs complexity, tools and methods are recommended with which the internal, external and entire complexity can be processed. The recommendation is based on the link of the methods with the related complexity driver as it is described in chapter 3.8. Therefore only
methods which directly influence the complexity the most are recommended.

To ensure the influence of the tools on the complexity, a selection method is invented which does not only consider the evaluated complexity driver itself but also the entire influence of the method on the LCs complexity.

This method takes the evaluation of the individual complexity driver (on the scale of 1-5) and multiplies it with their related emphasis. After each driver score is calculated their sum is computed which then is divided by the total number of complexity drivers.

\[
 f(x) = \sum_{i=1}^{n} \frac{(x_i \times y_i)}{n}
\]

\[
 x_i = \text{Driver evaluation}
\]

\[
 y_i = \text{Adjusted weighting}
\]

The procedure is done for both the internal and external complexity drivers separately. Finally the two results are aggregated which leads to a final score for each method. Based on this score a ranking is prepared and the methods with the highest scores are recommended. By suggest the method with the highest score, the highest improvement of the complexity is ensured.

If there is an unusual high internal or external complexity index there is also the possibility to select the methods with an high internal or
external score. Thereby the calculated individual scores are not aggregated.

Furthermore it is ensured that each Lead Centre gets the tools and methods recommended which suits best to their individual situation. When there are changes at the evaluation of the complexity driver also the list of recommended methods changes. However, the list is just a recommendation and not obligatory. The final selection of which methods will be used is in the responsibility of the accountable employee / manager.
4 Result

In the following section the achieved results of the project based on the used methods are described and expounded.

4.1 Clustered and sorted complexity drivers

Out of the literature there are 281 complexity drivers listed in total. Because an effective and efficient analysis of all available driver is not preferable, their number is reduced by eliminating those, which are in the meaning very similar as well as the obviously not applicable ones for FST. The reduction of the driver and their clustering is essential to get a better overview and following to avoid redundancies.

Therefore the complexity drivers are first sorted into internal and external drivers and then distributed into founded clusters. Due to the clusters the total number of internal and external complexity drivers is realized. The clusters as well as the number of drivers belonging to them are the following:

External Complexity Drivers:

- Market / Competition: All market- and competition-specific complexity drivers. 18 drivers in total.
- Customers: All complexity drivers who come into direct or indirect contact with customers. 10 drivers in total.
- Technology: Technological driven complexity drivers. 11 drivers in total.
Result

- **Environment**: Complexity drivers from the company environment. 8 drivers in total.
- **Other**: All other external complexity drivers which cannot be assigned unambiguously. 12 drivers in total.

**Internal Complexity Drivers:**
- **Products / Development**: Complexity drivers, which are directly or indirectly related to the product. 18 drivers in total.
- **Organization (company)**: Organizational complexity within the company is shown here. 33 drivers in total.
- **Value added**: Value-reducing complexity drivers. 11 drivers in total.
- **Processes**: Complexity that has its cause in the design procedure of the processes. 14 drivers in total.
- **Logistics**: Entrepreneurial complexity that occurs in connection with (internal & external) logistics. 7 drivers in total.
- **Other**: All other complexity drivers that cannot be directly associated with one of the previous categories. 15 drivers in total.

While the drivers were clustered a first pre-selection was done. The pre-selection focussed on drivers which are either to general (e.g. budget, logistics, production, etc.) or which had almost an identical meaning (e.g. organization strategy vs. department strategy).
In total there are **59 external** and **98 internal** complexity drivers in 11 classes left. A list with the drivers related to their classes can be seen in appendix 1.

### 4.2 Ishikawa-Diagram

Based on the drivers allocation into the clusters, an Ishikawa-diagram was created to structure the drivers more detailed and to find out which drivers affect the complexity direct or indirect by adding a second level as it can be seen in appendix 2.

With the transformation, classes inside the clusters are built and the drivers are allocated regarding their properties. Afterwards a selection of specific drivers was done which the survey candidates had to evaluate. When transferring the drivers into the Ishikawa, 13 external and 20 internal subcategories are founded. The subcategories for the internal and external drivers are the following:

**External Complexity Driver allocation:**

- **Technology:** Development, Product, Technologies
- **Market / Competition:** Competition, Market, Market changes, Needs
- **Customer:** Structure, Requirements
- **Environment:** Company Environment, Location
- **Other:** System, Logistics

**Internal Complexity Driver allocation:**

- **Processes:** Sales, Production, Planning
- **Value Creation**: Production control, Employees, Production process
- **Products / Development**: Assortment, Communication, Production, Product
- **Organization**: Staff, Process organization, Organizational structure, Strategy
- **Logistics**: Distribution, Inventory
- **Other**: Cost, Customer, System, Organization.

Because the selection of the driver was done regarding the Pareto-Principle (80 / 20 rule) the pre-selected drivers are reduced by approximately 80% which leads to a total number of **14 external** complexity drivers (reduction by 76.27%) and **18 internal** complexity drivers (reduction by 81.63%) as it can be seen in table 4 for the external and table 5 for the internal pre-selection.

<table>
<thead>
<tr>
<th>No.</th>
<th>Driver</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Development Partner</td>
<td>Technology</td>
</tr>
<tr>
<td>2</td>
<td>New Technological Innovations</td>
<td>Technology</td>
</tr>
<tr>
<td>3</td>
<td>Shortened Product Lifecycle</td>
<td>Technology</td>
</tr>
<tr>
<td>4</td>
<td>Technological Complexity</td>
<td>Technology</td>
</tr>
<tr>
<td>5</td>
<td>Market segmentation</td>
<td>Market/Competition</td>
</tr>
<tr>
<td>6</td>
<td>Differentiation Compulsion</td>
<td>Market/Competition</td>
</tr>
<tr>
<td>7</td>
<td>Competition Strategy</td>
<td>Market/Competition</td>
</tr>
<tr>
<td>8</td>
<td>Demand Complexity</td>
<td>Market/Competition</td>
</tr>
<tr>
<td>9</td>
<td>Market Requirements</td>
<td>Market/Competition</td>
</tr>
<tr>
<td>10</td>
<td>Number of Customers</td>
<td>Customer</td>
</tr>
<tr>
<td>11</td>
<td>Customer structure</td>
<td>Customer</td>
</tr>
</tbody>
</table>
Table 4: External Complexity Driver pre-selection.\(^7\)

<table>
<thead>
<tr>
<th>No.</th>
<th>Driver</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Number of Procurement items</td>
<td>Other</td>
</tr>
<tr>
<td>13</td>
<td>Number of ship-to addresses</td>
<td>Other</td>
</tr>
<tr>
<td>14</td>
<td>Number of Suppliers</td>
<td>Other</td>
</tr>
</tbody>
</table>

Table 5: Internal Complexity Driver pre-selection.\(^8\)

After the pre-selection of the driver only four classes (technology, market / competition, customer, and other) of the external and also

\(^7\) Cf. own table.
\(^8\) Cf. own table.
four classes (process, value creation, products/development, and organisation) of the internal drivers are left.

Due to the thinking that LCs are positioned on a global base, the environmental drivers can be seen as identical for each LC. Therefore the class “Environment”, from the external side, was not taken into consideration.

From the internal side the classes “Logistics” and “Other” are not represented in the pre-selection. While in the class “other” the drivers are evaluated as not important enough in comparison to the chosen ones, the class “Logistics” is supposed to be equally for each Lead-Centre worldwide.

4.3 Survey Evaluation

While answering to the survey the participants were asked a number of questions clustered in the three categories “General Information”; “Complexity Driver”, and “Complexity Tools and Methods” to get a better overview of the status of complexity management at FST.

The survey was sent to 177 candidates from where 72 participated the survey. From the received answers 11 are from Sales, 11 from Marketing, 5 are Operations Manager, 21 belong to the Engineering area, 18 are LC- or CC-managers and 6 belong to the Lean/Production/SCM department. As it is shown in figure 4, the highest respond rate is from the Engineering department with 65.63% followed by Lead- and Competence Centre with 48.65%. and Lean/
Production / SCM with 40% The lowest return quote has the Sales department with 22.92% although the highest absolute number of candidates with 48 is from this department. The overall return quote of the survey is 40.68%.

Due to the number of responses and the homogeneity of the candidates, the survey can be seen as representative.

4.3.1 General Information

To get an overview about if there is an active complexity management the candidates are asked to evaluate the complexity management intensity. Additionally the frequency of the complexity
management process is asked. Figure 5 shows that there are large differences between the processes of an active complexity management in the different departments. While Sales (9.1%) and Marketing (18.2%) have a low amount of complexity management has Lean/ Production / SCM (50%) and LC- / CC-manager (66.7%) a high amount.

The amount of complexity management can be set into correlation with the overall response rate of the survey. Then it can be implied that the response rate of the department is connected with the amount of an active complexity management. While the respond rates of Sales and Marketing are low, also their active complexity management process is low.

Not only can the respond rate be an indicator but also that the two departments are not directly related to the production process. When following this theory it can be implied that the amount of complexity management is correlated with the connection of the department to the production process.

Furthermore, the “Sales” department has a special position in the company. To avoid market competition between the individual LCs, the “Sales” department is outsourced from the LCs and structured as a “Corporate Department”.
Although the percentage share of “Yes” answers is heterogenic, the distribution of the “Sporadic” answers is homogenous. The difference between the highest (Operations Manager) and lowest (LC / CC-Manager and Engineering) amount is 26.7%. However, the interpretation of the answers must be taken carefully into consideration. There is the possibility that the candidates prefer to answer with “Sporadic” instead of “No” to provide a more positive picture regarding their own complexity management. However, the level of complexity management is distinct through all departments at FST.

Figure 5: Active Complexity Management per Department.\textsuperscript{10}

\textsuperscript{10} Cf. own illustration.
Regarding the production volume there are big differences in their distribution as it can be seen in figure 6. While the candidates were asked to specify their production volume according to the batch size (low, medium, and high), the term “Batch size” was not closer specified. Therefore differences within the interpretation of what is high, medium, and low can occur. However, a high batch size implies that the majority of the products are produced in form of mass production. The medium batch size has a production volume between mass production and job shop while the low batch size is mostly job shop or very low volume.

Figure 6: Production Volume Distribution.\textsuperscript{11}

\textsuperscript{11} Cf. own illustration.
If the candidate has another kind of production volume or is not related to production in any way there was also the possibility to answer with “Other”, e.g. Supply Chain Management. Although with 3% the proportion is low.

Almost half of the participants (48%) do not have changes in their production volume whereby the amount of High Batch with 19% is the highest. When there are no, or only few changes, the complexity can be seen as small. Otherwise the amount of those which have a high variation as a result of having all three kind of production volume amounts to 22% and is therefore almost as high as the amount of high batch size. Also the three biggest blocks with volume changes are aggregated 46% and therefore almost equally to the ones without changes. Conclusive it can be said that the distribution of the production volume is heterogenic.

4.3.2 Complexity Driver
In the second part of the survey the candidates had to evaluate the relevance and importance of the external and internal complexity driver. The evaluation scale goes from 1-5 whereby 1 is the lowest importance and 5 the highest. Furthermore they were asked to name additional driver which have, in their point of view, an impact on the organizations complexity and which should be taken into consideration.

Based on the evaluation an individual emphasis for each complexity driver results. Regarding the quantity and altitude of the individual
Result

Appraisal a score is calculated. By multiplying the valuation criteria (from 1 to 5) with the corresponding number of valuations, a weighted assessment of the complexity drivers is generated. To not sophisticate the results by not taking the “Not specified” answers into consideration, the product is divided by the total number of valid answers per driver and department.

\[ f(x) = \sum_{i=1}^{n} (\text{driver rank } x_i \times \text{respective participant } y_i) \]

The outcome for each driver in correlation with the department is shown in figure 7 for the external and in figure 10 for the internal complexity driver. As it can be seen the distribution of the assessment per department (Sales, Marketing, Operations Manager, Engineering, LC / CC Manager and Lean / Production / SCM) of the external driver is very homogenous. This means that the understanding of the external complexity is equally and furthermore does not distinguish between the departments.
Based on the individual calculation of the complexity drivers, a cross-section score is calculated. The same procedure is used as for the calculation of the individual score, but all responses are taken into account independently of their department. The ranking of the external complexity driver after the score calculation can be seen in figure 8.

Due to the total number of 72 candidates (N=72) who has partaken the survey, the maximum reachable scoring number per complexity

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12 Cf. own illustration.
driver is 360. Even no individual driver could reach this number, the “Market Requirements” are evaluated as the most important external complexity driver with a score of 301 followed by “Differentiation Compulsion” (292) and “Technological Complexity” (285). The at least important evaluated drivers are “Shortened Product Lifecycle” (190) and “Development Partner” (128).

![Bar chart showing external complexity driver ranked](image)

**Figure 8: External Complexity Driver Ranked.**

Due to the low evaluation of the driver “Development Partner” with an absolute score of 128 out of 360, which is less than half of the possible achievable score, it is decided that this driver is not representative to depict the external complexity. With respect to the individual ranking done by each department, which all ranked them

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13 Cf. own illustration.
on the last place, the driver is removed from the list of external complexity driver.

From the additional proposed complexity drivers, which are 28 in total, four main groups can be built. These are *Production* with 3 possible drivers, *Customer* with 12, *Environment* with 6 and *Other* with 7 suggestions.

Due to the answers given by the participants of the survey the drivers “Country-specific requirements” and “Customer requirements” are added, evaluated and ranked. The alternative complexity drivers are scored with 230 scoring points for “Customer requirements” and 200 for “Country-specific requirements”. This leads to both an alternative ranking and evaluation. The ranking of the additional complexity drivers is based on the number of proposals given by the participants.

Considering that approximately 50% of the proposals are related to the customer requirements, the driver is located in the middle of the ranking. The driver “Country-specific requirements” is located at the end of the ranking due to the lower number of proposals (approximately 20%) and the notes given by the participants which evaluates the driver with medium to low impact.

The new ranking can be seen in figure 9. Additionally to the total number of external drivers from 14 to 15 also the range has changed. While there was a difference of 173 scoring points between the first and last ranked driver, there is now a difference of 111 scoring points.
Due to the more balanced range the influence of the individual complexity driver on the complexity index decreases.

![Adjusted External Complexity Driver](image)

**Figure 9: Adjusted External Complexity Driver.**

For the overall reduction of the complexity drivers from the literature this means that 74.58% are not taken into consideration for the complexity of the SBUs.

In figure 10 the analysis of the internal complexity drivers, after their individual score was calculated, can be seen. In comparison to the external driver their distribution is heterogeneous. This can result because of two reasons:

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14 Cf. own illustration.
1. The understanding of the internal complexity is more different than of the external processes.

2. The participants are more familiar with their internal processes and therefore with the complexity at the own department.

Furthermore the range of the driver assessment is also strongly dependent on the department. While the participants from the Lean / Production / SCM department tend to evaluate the drivers lower than the average, the Sales department evaluate them higher. This can be because Lean / Production / SCM have a better understanding of complexity management and therefore they evaluate the complexity of the driver not as high than other departments. Moreover, when comparing the evaluation range with the fact that Sales evaluated the active complexity management with a low share, it can be derive that there is a correlation between the understanding and gathering of the internal complexity and their processing.
Based on the heterogeneous assessment distribution and the non-attendance of a redounding driver in a positive or negative direction, the ranking of the internal complexity driver is more balanced than the external.

While there is a maximum reachable score of 360 too, the difference from the most important ranked driver “Manufacturing technology” with a score of 284 to the less important ranked driver “Strategic

\[15\text{ Cf. own illustration.}\]
products” with a score of 211 only amounts 73 scoring points (in comparison to the external complexity driver ranking with a maximum difference of 173) as it can be seen in figure 11.

Due to the homogeneous evaluation without any derivation in a positive or negative direction no driver is removed. Furthermore there is no driver added. Although there are additional complexity drivers mentioned in the survey they are either captured by the description of the already existing ones or they are not seen important enough to be added.

**Figure 11: Internal Complexity Driver Ranked.**\(^{16}\)

\(^{16}\) Cf. own illustration.
Due to the balanced ranking the individual impact of the complexity drivers to the complexity index is minor which is shown and described more precise in chapter 4.4.

4.3.3 Complexity Tools and Methods
To reduce the impact of the complexity drivers, and therefore the LCs complexity, tools and methods are used. Due to the large number of them available, the participants were asked to evaluate them according to their usage and their strategy.

When analysing the results the usage frequency of the tools does not differ much. This means that most of the participants use them consistently, sporadic or their usage is planned. However, due to a not closer specified description of consistent and sporadic, the percental number still differs. For example a tool like “Segmentation” is used once per year or every two years is evaluated by some participants as consistent and by some as sporadic because of the long time frame. Nevertheless, the answers are homogeneous in all three main groups Lean / Production / SCM, Marketing & Sales, and Lead Centre and Competence Centre Managers.

In the Lean / Production / SCM group there are 37 tools to evaluate in total whereas 9 are marked as “Not specified” by more than 50% of the participants. From the Marketing & Sales group there are 24 tools prompted whereas again 9 of them are labelled as “Not specified” by more than 50%. One of the reasons is that this group does not use the tools than e.g. the Production department. Another one is, that some
the tools prompted are not in use anymore or they were developed and now conducted under another name. The largest tool box is located at the LC / CC-Managers with a total amount of 44. The large number comes from their area of accountability which includes all departments at least partly. Therefore the percentage of tools which are not used by more than 50% amounts to 5.

The tools and methods which are not used by more than 50% of the participants are not taken into consideration. This does not mean that they are not used at FST at all, but they must be analysed to figure out the reasons why they are only used by a small number of participants.

Even the usage frequency of the methods is homogeneous, their strategy is not. For the majority of the participants it is unknown if they are used for complexity –reduction, -control, or –prevention independently of the department. This implies that they are actively used but it is not known for what exactly. Due to the wide distribution of the answers the strategy for each tool and method must be clarified and defined otherwise a successful complexity management is very difficult to implement.

### 4.4 Tool description layout

While the applicability of the tools and methods is clear a description layout with which a short overview of the different tools is provided. The layout is divided into eight sections as it can be seen in figure 12. The sections are the “Tool name”, “Description”, “Applicability”, “Preconditions”, “Time frame”, “Responsibility”, “Further
information”, and the internal and external “Complexity Driver”. Furthermore there is the possibility to attach additional notes when necessary. The allocation of the driver into internal and external is because of two reasons:

1. The assignment of the drivers to the methods is easier. Furthermore it is clearer if the method has more influence on the internal or the external complexity.
2. When there is an unusual high internal or external Complexity Index at a LC, the selection of the method can happen due to only the internal or external complexity driver calculation and not the entire as it is described in chapter 3.11.

With the information provided in the layout the worker / manager should be in the position to use the methods without being an expert in that field.

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Name of the tool (e.g. Segmentation, Focused Factory, VSM, …)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Short description about what the tool will do and how it works. The description should not be longer than four-five lines.</td>
</tr>
</tbody>
</table>
| Applicability | Level and / or area of applicability  
➢ Factory, Warehouse, Customer  
➢ Logistics & SCM, Marketing & Sales,  
➢ First level tool; second level tool |
| Preconditions | Depending on the level and applicability: E.g. methods which must be done before tool can be used (5S, 7 types of waste, VSM) |
The layout was chosen to keep method description short. It shall only provide an overview without any deeper information. If further information is needed there is the possibility to contact the Subject Matter Expert (SME) or to follow the included link which leads to a document where a complete description is deposited. Furthermore it shall simplify the search and finding of possible usable complexity reduction tools.

Although the recommendation for tools and methods goes electronically there is additionally a handout provided to the LC / CC-Manager where the method of complexity management including a

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17 Cf. own illustration.
short background, the drivers and tools are described. Here the filled-in tool layout is included, too.

To ensure a convenient recommendation of methods, they are connected with the dedicated drivers. To simplify the distribution of the tools to the complexity drivers they are apportioned to their field of application as following (a complete list of the methods connected to the drivers is attached in the appendix 5):

- Lean with 20 methods
- Supply Chain Management with 6 methods
- Purchase and Procurement with 7 methods
- Corporate Function with 12 methods
- Marketing and Sales with 15 methods.

Notwithstanding that there are more than the mentioned number of methods, only those which are used sporadic or consistent by more than 50% of the survey participants are taken into consideration.

As required there is at least one tool or method connected to each internal and external complexity driver. Nevertheless, for some more tools have to be found to ensure a valid complexity management.

The department distribution is heterogenic even there are two driver classes which are dominated by one department. First there is the Value Creation class with a majority of Lean tools and methods. This is because most of the complexity drivers in this class belong to the production of components Lean has more direct influence than other
departments. Same goes for the Market / Competition driver class which is dominated by the Marketing and Sales department.

Although the complexity drivers are connected and therefore influencable by different methods there are also influences between the drivers itself. A change of one driver can lead to a change of other drivers (e.g. degree of labour and purchase strategy). Furthermore, tools and methods are influencing directly or indirectly several drivers at a time. Again there is the risk of adjusting several drivers simultaneously which can lead to a result which is not preferred.

Therefore the usage of the methods cannot be thought with linear thinking and must be thought through. By using one tool to decrease one complexity driver other drivers may be increased.

4.5 Emphasis Method

Based on the survey and the consequent evaluation of the internal and the external complexity driver an emphasis method is provided. With the emphasis method the drivers are weighted to ensure a consequent importance of the ranking. Due to the individual score they reached as it is described in chapter 4.3.2, their importance is taken into account for the determination of the LCs CI.

On the basis of this evaluation the sum of each individual score \( (x_i) \) is divided by the sum of the scores. The result is multiplied by 100 to get a percentage of each driver.
\[ f(x) = \frac{x_i}{\sum_{i=1}^{n} x_i} \times 100 \]

For the external complexity driver there is a discrepancy of 5.29% from the highest ranked driver to the lowest one. However the difference to an equally weighted evaluation is 2.06% from the highest and 3.23% from the lowest driver as shown in table 6.

<table>
<thead>
<tr>
<th>No.</th>
<th>Driver</th>
<th>Score</th>
<th>Evaluation</th>
<th>Adjusted Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Market Requirements</td>
<td>301</td>
<td>7,14%</td>
<td>9,20%</td>
</tr>
<tr>
<td>2</td>
<td>Differentiation Compulsion</td>
<td>292</td>
<td>7,14%</td>
<td>8,93%</td>
</tr>
<tr>
<td>3</td>
<td>Technological Complexity</td>
<td>285</td>
<td>7,14%</td>
<td>8,72%</td>
</tr>
<tr>
<td>4</td>
<td>Competition Strategy</td>
<td>281</td>
<td>7,14%</td>
<td>8,59%</td>
</tr>
<tr>
<td>5</td>
<td>Number of Customers</td>
<td>250</td>
<td>7,14%</td>
<td>7,65%</td>
</tr>
<tr>
<td>6</td>
<td>Customer structure</td>
<td>234</td>
<td>7,14%</td>
<td>7,16%</td>
</tr>
<tr>
<td>7</td>
<td>Demand Complexity</td>
<td>229</td>
<td>7,14%</td>
<td>7,00%</td>
</tr>
<tr>
<td>8</td>
<td>New Technological Innovations</td>
<td>229</td>
<td>7,14%</td>
<td>7,00%</td>
</tr>
<tr>
<td>9</td>
<td>Number of Procurement items</td>
<td>217</td>
<td>7,14%</td>
<td>6,64%</td>
</tr>
<tr>
<td>10</td>
<td>Market segmentation</td>
<td>215</td>
<td>7,14%</td>
<td>6,57%</td>
</tr>
<tr>
<td>11</td>
<td>Number of Suppliers</td>
<td>210</td>
<td>7,14%</td>
<td>6,42%</td>
</tr>
<tr>
<td>12</td>
<td>Number of ship-to addresses</td>
<td>209</td>
<td>7,14%</td>
<td>6,39%</td>
</tr>
<tr>
<td>13</td>
<td>Shortened Product Lifecycle</td>
<td>190</td>
<td>7,14%</td>
<td>5,81%</td>
</tr>
<tr>
<td>14</td>
<td>Development Partner</td>
<td>128</td>
<td>7,14%</td>
<td>3,91%</td>
</tr>
</tbody>
</table>

|       |                               |       | 100%       | 100%               |

Table 6: External Complexity Driver Weighted.\(^{18}\)

Due to the changes at the external requirements (see chapter 4.3) the evaluation as well as the adjusted evaluation changes, too. As it can be seen in table 7 the evaluation decreases due to the adding of one

\(^{18}\) Cf. own table.
additional complexity driver. The discrepancy therefore changes, too, to a maximum difference of 3.11% from the highest “Market Requirements” to the lowest “Shortened Product Lifecycle”. Moreover, the difference to the equal evaluation amounts 1.76% and 1.35%.

<table>
<thead>
<tr>
<th>No.</th>
<th>Driver</th>
<th>Score</th>
<th>Evaluation</th>
<th>Adjusted Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Market Requirements</td>
<td>301</td>
<td>6.67%</td>
<td>8.43%</td>
</tr>
<tr>
<td>2</td>
<td>Differentiation Compulsion</td>
<td>292</td>
<td>6.67%</td>
<td>8.17%</td>
</tr>
<tr>
<td>3</td>
<td>Technological Complexity</td>
<td>285</td>
<td>6.67%</td>
<td>7.98%</td>
</tr>
<tr>
<td>4</td>
<td>Competition Strategy</td>
<td>281</td>
<td>6.67%</td>
<td>7.87%</td>
</tr>
<tr>
<td>5</td>
<td>Number of Customers</td>
<td>250</td>
<td>6.67%</td>
<td>7.00%</td>
</tr>
<tr>
<td>6</td>
<td>Customer Structure</td>
<td>234</td>
<td>6.67%</td>
<td>6.55%</td>
</tr>
<tr>
<td>7</td>
<td>Customer Requirements</td>
<td>230</td>
<td>6.67%</td>
<td>6.44%</td>
</tr>
<tr>
<td>8</td>
<td>Demand Complexity</td>
<td>229</td>
<td>6.67%</td>
<td>6.41%</td>
</tr>
<tr>
<td>9</td>
<td>New Technological Innovations</td>
<td>229</td>
<td>6.67%</td>
<td>6.41%</td>
</tr>
<tr>
<td>10</td>
<td>Number of Procurement items</td>
<td>217</td>
<td>6.67%</td>
<td>6.08%</td>
</tr>
<tr>
<td>11</td>
<td>Market Segmentation</td>
<td>215</td>
<td>6.67%</td>
<td>6.02%</td>
</tr>
<tr>
<td>12</td>
<td>Number of Suppliers</td>
<td>210</td>
<td>6.67%</td>
<td>5.88%</td>
</tr>
<tr>
<td>13</td>
<td>Number of Ship-to addresses</td>
<td>209</td>
<td>6.67%</td>
<td>5.85%</td>
</tr>
<tr>
<td>14</td>
<td>Country-specific requirements</td>
<td>200</td>
<td>6.67%</td>
<td>5.60%</td>
</tr>
<tr>
<td>15</td>
<td>Shortened Product Lifecycle</td>
<td>190</td>
<td>6.67%</td>
<td>5.32%</td>
</tr>
</tbody>
</table>

Table 7: Alternative Ranking External Complexity Driver.\(^{19}\)

For the internal complexity drivers the calculation for the evaluation of the complexity index is identical to the external. Table 8 shows the adjusted evaluation of the internal complexity drivers and their

\(^{19}\) Cf. own table.
differences. As it can be seen the difference from the as most important evaluated driver “Manufacturing technology” to the as least important evaluated driver “Strategic product” amounts 1.64%. Furthermore the derivation to the equally balanced evaluation is 0.81% and 0.83%. Therefore the impact of the individual driver on the entire complexity is slight.

<table>
<thead>
<tr>
<th>No.</th>
<th>Driver</th>
<th>Score</th>
<th>Evaluation</th>
<th>Adjusted Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manufacturing technology</td>
<td>284</td>
<td>5.56%</td>
<td>6.37%</td>
</tr>
<tr>
<td>2</td>
<td>Diversity of raw materials</td>
<td>273</td>
<td>5.56%</td>
<td>6.12%</td>
</tr>
<tr>
<td>3</td>
<td>Main production process</td>
<td>273</td>
<td>5.56%</td>
<td>6.12%</td>
</tr>
<tr>
<td>4</td>
<td>Number of production process</td>
<td>268</td>
<td>5.56%</td>
<td>6.01%</td>
</tr>
<tr>
<td>5</td>
<td>Number of products</td>
<td>267</td>
<td>5.56%</td>
<td>5.99%</td>
</tr>
<tr>
<td>6</td>
<td>Individualization of production processes</td>
<td>266</td>
<td>5.56%</td>
<td>5.96%</td>
</tr>
<tr>
<td>7</td>
<td>Quality standards</td>
<td>266</td>
<td>5.56%</td>
<td>5.96%</td>
</tr>
<tr>
<td>8</td>
<td>Structure of production system</td>
<td>258</td>
<td>5.56%</td>
<td>5.78%</td>
</tr>
<tr>
<td>9</td>
<td>Complexity of LC structure</td>
<td>252</td>
<td>5.56%</td>
<td>5.65%</td>
</tr>
<tr>
<td>10</td>
<td>Depth of development</td>
<td>248</td>
<td>5.56%</td>
<td>5.56%</td>
</tr>
<tr>
<td>11</td>
<td>Department orientation</td>
<td>235</td>
<td>5.56%</td>
<td>5.27%</td>
</tr>
<tr>
<td>12</td>
<td>Engineering services</td>
<td>234</td>
<td>5.56%</td>
<td>5.25%</td>
</tr>
<tr>
<td>13</td>
<td>Product management</td>
<td>230</td>
<td>5.56%</td>
<td>5.16%</td>
</tr>
<tr>
<td>14</td>
<td>Degree of labour</td>
<td>226</td>
<td>5.56%</td>
<td>5.07%</td>
</tr>
<tr>
<td>15</td>
<td>Organizational structure</td>
<td>226</td>
<td>5.56%</td>
<td>5.07%</td>
</tr>
<tr>
<td>16</td>
<td>Purchase strategy</td>
<td>222</td>
<td>5.56%</td>
<td>4.98%</td>
</tr>
<tr>
<td>17</td>
<td>Product family</td>
<td>222</td>
<td>5.56%</td>
<td>4.98%</td>
</tr>
<tr>
<td>18</td>
<td>Strategic products</td>
<td>211</td>
<td>5.56%</td>
<td>4.73%</td>
</tr>
</tbody>
</table>

100% 100%
By adjusting the evaluation for the drivers the importance of them according to the survey is considered. With the calculation it is ensured that the as more important assessed driver is also weighted more than the as least important assessed.

4.6 Complexity Index

To demonstrate the model a generic test-run with one of the Lead Centres was done. The approach there is to assess the internal and external complexity drivers and calculate the internal, external and entire complexity index subsequently. To capture the complexity the survey is filled out with data according to the pre-defined scale from 1 to 5.

The Lead Centre belongs to the division “Special Sealing” and consists one Competence Centre and three Partner Productions in two different countries.

Resulting out of the evaluation the internal complexity is distributed heterogenic through the complexity drivers and their classes. While the class Processes is significant rated as most complex the class Products/Development is rated as the least complex. The other two classes Value Creation and Organization are assessed similar as medium complex as it can be seen in figure 13.

---

20 Cf. own table.
Based on this evaluation the **Internal Complexity Index** is calculated and results with a score of **2.47**. Due to the scale is from 1-5 the internal complexity is located in the lower half of the possible maximum reachable complexity score.

The evaluation of the external complexity can be seen in figure 14. The assessment of the individual drivers results in a high amplitude of the *Customer* class. The at least complex assessed driver class is *Other* with a range over all drivers from 1-3. Also the drivers “Market requirements” and “Differentiation compulsion” belonging to the

---

21 Cf. own illustration.
class *Market / Competition* are evaluated with a high score whereas the other drivers of this class are evaluated as few complex.

![External Complexity Driver](image)

**Figure 14: External Driver LC SSA.**

Resulting the **External Complexity Index** with a score of **2.68** is located in the lower half of the possible maximum reachable complexity score, too.

Due to the very similar internal and external complexity index the entire complexity index of the Lead Centre, the quotient of the external and the internal complexity index, appears to be exactly **1.09**. Hence it means the external and the internal complexity is equally distinctive as it can be seen in figure 15.

---

22 Cf. own illustration.
Although the Complexity Index is 1.09 which is the striven for status it does not mean that the condition is perfect. On the contrary the complexity drivers with high amplitude have to be examined closely to see if they can be improved.

Starting with the complexity drivers with amplitude of 5 the following tools and methods are recommended to reduce their complexity.

Figure 15: Complexity Index Overview.\textsuperscript{23}

\textsuperscript{23} Cf. own illustration.
- *Purchase strategy*: Risk Management, Global Sourcing, Economic Order Quantity, Make-or-Buy, and Forecast Update.


- *Customer requirements*: Total Quality Management.

Although there are a number of tools which are applicable their practicalness and impact must be figured out and the final decision is done by the responsible manager.
5 Discussion and Future work

Finally, the content of the work is critically discussed and summarized in a conclusion. Furthermore, the limitations of the applicability are shown and an outlook on future research needs is given.

5.1 Discussion

The objective of the project was to develop a model with which the internal and external complexity of the LCs can be detected, evaluated and processed. After completing the work it can be said that the results were able to generally capture the LCs complexity internally as well as externally. Besides the detection of the complexity it is furthermore possible to assess the internal and external as well as the entire LCs complexity. Finally the processing of the complexity can be taken based on the assessment.

The foundation of the complexity management is the identification and evaluation of the complexity driver. Without an accurate, applicable-related, selection of the internal and external complexity driver the result of the CI is sophisticated. There will be a score which shows the complexity of the LC but it will not represent their complexity accurate. The selection of the drivers is done based on the literature and the high understanding of complexity at FST. Therefore their eligibility was done with high expertise and the driver chosen represents the organization’s structure.
The weighting of the drivers as well as the calculation of the complexity index is done with mathematical logic. When comparing the CI with similar methods from the literature it shows a clear statistical index which is the base for the recommendation of complexity processing tools and methods.

The tools and methods chosen are also done with high expertise from the company. Due to the selection of appropriate methods by the responsible experts it can be said that they are suitable to process the complexity. Also their connection with the drivers was done with the experts and therefore their impact on the complexity drivers can be seen as valid. However, their full impact can be seen in long-term, therefore an interpretation of the impact on the LCs complexity cannot be done yet.

By assessing the complexity of one Lead Centre their high and low distinct internal and external complexity is determined. Resulting the field of improvement is shown and the overall complexity of the LC. The next step would now be to use some of the tools recommended and measure their impact on the complexity evolution.

Conclusive the project can be seen as successful. The relevant complexity drivers are ascertained, their weighting factors acquired and a complexity index was introduced. Furthermore tools and methods to process the complexity are gathered and connected to the complexity driver. Based on these results recommendations for actions are taken.
Although the model works there are some limitations regarding their applicability. Due to the structure of FST in SBUs the driver selection is much specified. Furthermore, when there are significant changes in the company’s environment they have to be policed regarding their topicality. Depending on their currentness, the driver selection is still valuable or they have to be adjusted.

However, the complexity management shall be done **annually**. When using the index as a foundation the changes of the complexity of the individual Lead Centres can be detected and it can be seen if the complexity increased, decreased or is constant. Furthermore, the LCs can be compared to figure out reasons for different indexes while there are comparable circumstances. The complexity management is not a static but a dynamic procedure.

### 5.2 Future Work

Due to the questions which appeared while proceeding the thesis, there are several possibilities for topic-related future works.

*Project extension*

To continue with the project at FST, new complexity drivers for different levels through the whole organization can be identified and named. With these drivers the previously described methods can be used to process complexity on different levels in the organization as well as along the whole value chain.
Discussion and Future work

**Complexity Expansion**
While the complexity index for LC level is developed it can be adapted by other company levels or departments. Because the model is working the complexity drivers can be adjusted according to the level of use and the whole procedure can be repeated.

**Complexity Controlling**
To keep the level of complexity stable and to keep track of the complexity costs, complexity controlling can be launched. For the complexity controlling cost accounting and a complexity scorecard can be developed as well as a complexity operating number model. By actively operate a complexity controlling there are other possibilities to reduce, handle, and control the internal and external complexity.

**Complexity prevention**
To not only reduce and control complexity but also to prevent it is an interesting and challenging project to develop a method with which the complexity can be identified and processed before it appears. The questions hereby are, if there is a possibility to develop a tool with which possible occurring complexity can be detected before it appears. Furthermore a method to avoid internal and external complexity on a certain level can be investigated.
**Publication bibliography**


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Jäger, Jens; Kluth, Andreas; Schatz, Anja; Bauernhansl, Thomas (2014): Complexity Patterns in the Advanced Complexity Management of Value Networks. In Variety Management in Manufacturing Proceedings of the 47th CIRP Conference on


**Kluth, Andreas; Jäger, Jens; Schatz, Anja; Bauernhansl, Thomas (2014b):** Method for a Systematic Evaluation of Advanced...


**Lindemann, Udo; Maurer, Maik; Braun, Thomas (2009):** Structural complexity management. An approach for the field of product design. Berlin: Springer.


Appendixes

Appendix 1: Complexity driver pre-selection

External Complexity Driver

<table>
<thead>
<tr>
<th><strong>Market / competition</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited increase in market volume</td>
<td></td>
</tr>
<tr>
<td>Deregulation of the markets</td>
<td></td>
</tr>
<tr>
<td>Differentiation compulsion (competition)</td>
<td></td>
</tr>
<tr>
<td>Increase the intensity of competition</td>
<td></td>
</tr>
<tr>
<td>Globalization of markets</td>
<td></td>
</tr>
<tr>
<td>Buyer markets</td>
<td></td>
</tr>
<tr>
<td>Macroeconomics</td>
<td></td>
</tr>
<tr>
<td>Market and competitive requirements</td>
<td></td>
</tr>
<tr>
<td>Market dynamics</td>
<td></td>
</tr>
<tr>
<td>Market fragmentation (distribution)</td>
<td></td>
</tr>
<tr>
<td>Demand complexity</td>
<td></td>
</tr>
<tr>
<td>Decreasing marketing times</td>
<td></td>
</tr>
<tr>
<td>Range size</td>
<td></td>
</tr>
<tr>
<td>Stagnant prices</td>
<td></td>
</tr>
<tr>
<td>Change the markets / market structure</td>
<td></td>
</tr>
<tr>
<td>Competition activities</td>
<td></td>
</tr>
<tr>
<td>Complexity of competition</td>
<td></td>
</tr>
<tr>
<td>Competitive strategy</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Customers</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Request diversity / customization of the demand</td>
<td></td>
</tr>
<tr>
<td>Functional requirements</td>
<td></td>
</tr>
<tr>
<td>Size of the target group</td>
<td></td>
</tr>
<tr>
<td>Customer requirements</td>
<td></td>
</tr>
<tr>
<td>Customer number</td>
<td></td>
</tr>
<tr>
<td>Customer structure</td>
<td></td>
</tr>
<tr>
<td>Demand complexity</td>
<td></td>
</tr>
<tr>
<td>Need the individualized production (demand individuality)</td>
<td></td>
</tr>
<tr>
<td>Product requirements</td>
<td></td>
</tr>
<tr>
<td>Unforeseen variability of demand (demand surge)</td>
<td></td>
</tr>
</tbody>
</table>
### Technology
- Decreasing opportunities for technological product differentiation
- Development of communication and information technology
- Development partner
- New key technologies
- Increasing number of technologically exploitable research results
- Rising costs for innovations
- Technical progress
- Technological complexity
- Availability of technologies
- Shortened product life cycles
- Short technology life cycles

### Environment
- Waste management strategy
- Geographical factors
- Statutory requirements and legal system
- Globalization
- Complexity of economic systems
- Country-specific topics
- Ecological and cultural factors
- Political environment (instabilities)
<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of procurement items</td>
</tr>
<tr>
<td>Number of suppliers</td>
</tr>
<tr>
<td>Number of external interfaces</td>
</tr>
<tr>
<td>Dynamic behaviour of the system</td>
</tr>
<tr>
<td>Heterogeneity of order backlog</td>
</tr>
<tr>
<td>Horizontal building structure</td>
</tr>
<tr>
<td>Coupling with services</td>
</tr>
<tr>
<td>Customer and supplier base</td>
</tr>
<tr>
<td>Lack of transmission of information about customer requirements from existing to new products</td>
</tr>
<tr>
<td>Marketing, sales and service concept</td>
</tr>
<tr>
<td>Available know-how of suppliers</td>
</tr>
<tr>
<td>Reduction of delivery times</td>
</tr>
</tbody>
</table>
Internal Complexity Driver

<table>
<thead>
<tr>
<th>Products/Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity of the production program planning</td>
</tr>
<tr>
<td>Number of variants</td>
</tr>
<tr>
<td>Number of raw materials/parts and assemblies of a product</td>
</tr>
<tr>
<td>Number of used parts / materials / components</td>
</tr>
<tr>
<td>Width of the range</td>
</tr>
<tr>
<td>Degree of diversification of the variants</td>
</tr>
<tr>
<td>Missing construction methodology</td>
</tr>
<tr>
<td>Heterogeneity of the production programme</td>
</tr>
<tr>
<td>Product design</td>
</tr>
<tr>
<td>Product complexity (custom variants)</td>
</tr>
<tr>
<td>Product structure</td>
</tr>
<tr>
<td>Product variability</td>
</tr>
<tr>
<td>Maturity of the finished product (Variant complexity / depth of development)</td>
</tr>
<tr>
<td>Structure of the production programme</td>
</tr>
<tr>
<td>Different variant definition</td>
</tr>
<tr>
<td>Incomplete version information</td>
</tr>
<tr>
<td>Diversity of raw materials/parts and components of a product</td>
</tr>
<tr>
<td>Distributed version information</td>
</tr>
<tr>
<td><strong>Organization (company)</strong></td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>Deportation of responsibility</td>
</tr>
<tr>
<td>Number on an order fulfilment of involved employees</td>
</tr>
<tr>
<td>Number of levels of organization</td>
</tr>
<tr>
<td>Number of sites</td>
</tr>
<tr>
<td>Structure and process organisation</td>
</tr>
<tr>
<td>Expression of the form being</td>
</tr>
<tr>
<td>Range of markets</td>
</tr>
<tr>
<td>Area egoism / selfishness</td>
</tr>
<tr>
<td>Number of employees</td>
</tr>
<tr>
<td>Duration of the decision-making processes</td>
</tr>
<tr>
<td>Diversification in the business areas</td>
</tr>
<tr>
<td>Purchasing strategy</td>
</tr>
<tr>
<td>Missing strategy</td>
</tr>
<tr>
<td>Function orientation</td>
</tr>
<tr>
<td>Business form</td>
</tr>
<tr>
<td>Degree of labour / centralization degree</td>
</tr>
<tr>
<td>Information asymmetry</td>
</tr>
<tr>
<td>ICT system misfit</td>
</tr>
<tr>
<td>Control bodies</td>
</tr>
<tr>
<td>Long decision paths and processes</td>
</tr>
<tr>
<td>Power quest</td>
</tr>
<tr>
<td>Lack of motivation/identification with corporate goals</td>
</tr>
<tr>
<td>Lack of social and professional competence</td>
</tr>
<tr>
<td>Poor organisational integration</td>
</tr>
<tr>
<td>Media breaks</td>
</tr>
<tr>
<td>Negative emotions</td>
</tr>
<tr>
<td>Organizational complexity</td>
</tr>
<tr>
<td>Organisational separation of task, responsibility and competence</td>
</tr>
<tr>
<td>Corporate strategy</td>
</tr>
<tr>
<td>Insufficient definition and recording the complexity in the targets of the company</td>
</tr>
<tr>
<td>Lack of opportunities to review/capture the complexity</td>
</tr>
<tr>
<td>Lack of opportunities for capturing costs moderate complexity</td>
</tr>
<tr>
<td>Number of hierarchy levels</td>
</tr>
</tbody>
</table>
## Value creation
- Number of internal interfaces / interfaces
- Results of work of each employee
- Type of task coordination (drop-off / collection system)
- Stocking levels
- Manufacturing technology
- Manufacturing depth
- Main function orientation
- Heterogeneity of the composition of the order backlog
- Complexity of resources
- Staff specialization
- Changing use subset

## Processes
- Wide product range
- Planning type
- Manufacturing process
- Production expiration type
- Degree of Division of labour
- Degree of systematization
- Degree of mechanisation
- Complex production technologies / alternative manufacturing processes
- Complexity of production processes
- Coupling with services
- Marketing, sales and service concept
- Quality management
- Number of different processing times/stations
- Complexity of the production system

## Logistics
- Number of items in stock
- Number of stock movements
- Number of transport sources
- Procurement volume
- Stocks
- Delivery speed
- Quantity per bearing removal
### Other

<table>
<thead>
<tr>
<th>Current costs set limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of resources to coordinating and areas</td>
</tr>
<tr>
<td>Heterogeneity of the customers</td>
</tr>
<tr>
<td>Lack of information regarding complexity relevant information into existing reports and documents</td>
</tr>
<tr>
<td>Flood information</td>
</tr>
<tr>
<td>Communication and interaction between of the departments of</td>
</tr>
<tr>
<td>Customer complexity</td>
</tr>
<tr>
<td>Lack of transparency</td>
</tr>
<tr>
<td>Quantity and degree of fragmentation of customer groups</td>
</tr>
<tr>
<td>Method deficit</td>
</tr>
<tr>
<td>Reduction of production costs</td>
</tr>
<tr>
<td>Jump Fixer capacity building</td>
</tr>
<tr>
<td>Trade-offs</td>
</tr>
<tr>
<td>Objectives - and control deficit: Openness of target systems with respect to the complexity</td>
</tr>
<tr>
<td>Increasing networking</td>
</tr>
</tbody>
</table>
Appendix 2: Ishikawa-Diagram

[Image of Ishikawa Diagram]

- **External Complexity Drivers**
  - Market globalization
  - Market deregulation
  - Market changes
  - Competition
  - Need for market requirements
  - Stagnant markets
  - Decreasing prices
  - Decreasing marketing times
  - Limited increase in market volume
  - Macro-economics
  - Market dynamics
  - Market segmentation
  - Decreasing marketing times
  - Change the markets/market structure
  - Demand complexity
  - Differentiation compulsion
  - Increase the intensity of competition
  - Competition strategy
  - Competition activities
  - Customer structure
  - Unforeseen variability of demand (demand surge)
  - Functional requirements
  - Requirements
  - Size of the target group
  - Number of customers
  - Customer requirements
  - Product requirements
  - Request diversity/customization of the demand
  - Development
  - Product Technologies
  - Development of communication and information technology
  - Development partner
  - New key technologies
  - Rising costs for innovation
  - Technical progress
  - Increasing number of technologically exploitable research results
  - Technological complexity
  - Availability of technologies
  - Decreasing opportunities for technical product differentiation
  - Shortened product life cycle
  - Shortened technology life cycles
  - Location
  - Company environment
  - Waste management
  - Globalization complexity of economic systems
  - Geographical factors
  - Environmental and cultural factors
  - Statutory requirements and legal system
  - Country-specific topics
  - Political environment
  - Logistics
  - Number of suppliers
  - Available know-how of suppliers
  - Reduction of delivery times
  - Number of shipping addresses
  - Number of procurement items
  - Number of external interfaces
  - Dynamic behavior of the system
  - Heterogeneity of the order backlog
  - Lack of transmission of information about customer requirements from existing to new products
  - Marketing, sales, and service concept
  - Coupling with services
  - Systems
  - Availability of know-how of suppliers
  - Number of employees
  - Number of suppliers
  - Number of marketing strategies
  - Forecasting sales
  - Demand planning
  - Inventory management
  - Redundant stock
  - Redundant procurement items
  - Logistical planning
  - Availability of know-how of suppliers
  - Number of employees
  - Number of suppliers
  - Number of marketing strategies
  - Forecasting sales
  - Demand planning
  - Inventory management
  - Redundant stock
  - Redundant procurement items
  - Logistical planning

---

*Appendixes*
Appendix 3: Survey

General Information

**Question 1:** In which segment is your main business located (multiple answers possible).

- [ ] Automotive
- [ ] Fluid Technologies (Appliances, Building Engineering, Fluid Handling, Fluid Power, Health, Safety)
- [ ] Heavy Industry (Commercial Marine, Forming Machines, Metal Processing, Mining, Pulp and Paper)
- [ ] Mobile Machinery (Agriculture, Construction, Material Handling)
- [ ] Mobility (Aerospace, Railway, Recreational)
- [ ] Power (Energy, Machine Tools, Power Generation, Power Tools, Power Transmission)
- [ ] Process Industry (Food & Beverage, Chemical, Pharmaceutical)
- [ ] Distribution
- [ ] Subsidiaries

**Question 2:** Please specify your main production volume process (multiple answers possible).

- [ ] Low Batch Size Production
- [ ] Medium Batch Size Production
- [ ] High Batch Size Production
- [ ] Other

**Question 3:** Please specify your customer structure (multiple answers possible).

- [ ] Catalogue Customer
- [ ] Industrial Customer
- [ ] Automotive & Tier 1

**Question 4:** Please state the department you are working in/belonging to.

- [ ] Sales
- [ ] Marketing
- [ ] Operations manager
- [ ] LC/CC Manager
- [ ] Engineering
- [ ] Lean/Growth/SCM
Question 5: Do you/your department actively process complexity management?

- Yes
- No
- Sporadic/partly
- Unknown

Complexity Drivers

Question 6/8: To get an indicator regarding the importance of the complexity drivers, the first question asks the importance of the drivers at FST. The importance is segmented into 5 distinctions which goes form “less important” (the driver has only few importance) over “important” (the driver is more important) till “very important” (the driver has high influence at the company). If the driver does not have any influence there is also the possibility to mark those with “not specified”.

Please evaluate the internal/external driver regarding their importance.

<table>
<thead>
<tr>
<th>Driver</th>
<th>Less important</th>
<th>Important</th>
<th>Very Important</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Question 7/9: If there are other internal/external complexity drivers which are not mentioned above but which may be influencing the complexity strongly, you are welcome to name them. As a reference you may use the Ishikawa-diagram (attached in the email) where other drivers are listed.
**Complexity Process Tools/Methods**

To process the complexity drivers there are several tools available with which the complexity can actively be influenced. Following I’d ask you to name the tools you already use and the pursue of them. The section includes three questions whereas the first and the second are to gather the tools already used and the third to gather their strategy.

**Question 10:** To process the complexity there are different Complexity Process Tools at FST. The first question is to find out which tools are actively used at FST and how their importance regarding the applicability and effect is. Therefore the answer possibilities are separated and ranked from Less important over Important to Very important. If the listed tool is not use, please mark the Tool with “Not specified”.

Which of the following management tools/methods do you actively use?

<table>
<thead>
<tr>
<th>Tool/Method</th>
<th>Planned for usage</th>
<th>Sporadic</th>
<th>Consistently</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

**Question 11:** If there are other tools in use which are not mentioned yet you are welcome to name them.

<p>| | |</p>
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</table>

**Question 12:** By processing the complexity, there are different strategies depending on their time frame. The first strategy is to reduce Complexity which can be seen as a short-term strategy. The Mid-term strategy is to control the level of complexity and long-term the objective is to prevent complexity.

In the following question can you please name the objective of the used tools? If the tool is not used you can mark it with “not specified”.

<p>| | |</p>
<table>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

99
<table>
<thead>
<tr>
<th>Tool</th>
<th>Complexity Reduction</th>
<th>Complexity Control</th>
<th>Complexity Prevention</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**Appendix 4: Tool description layout**

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Name of the tool (e.g. Segmentation, Focused Factory, VSM,...)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Short description about what the tool will do and how it works. The description should not be longer than four-five lines.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applicability</th>
<th>Level and/or area of applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>➢ Factory, Warehouse, Customer</td>
</tr>
<tr>
<td></td>
<td>➢ Logistics &amp; SCM, Marketing &amp; Sales,</td>
</tr>
<tr>
<td></td>
<td>➢ First level tool; second level tool</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preconditions</th>
<th>Depending on the level and applicability: E.g. methods which must be done before tool can be used (5S, 7 types of waste, VSM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Short-term, mid-term, long-term project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exact number of weeks if possible, but not required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Responsibility</th>
<th>Can be a person or a department</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perhaps Subject-Matter Expert</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Further information</th>
<th>Here could be a link to SharePoint/Platform where a detailed description is deposited.</th>
</tr>
</thead>
</table>
## Appendix 5: Methods and tools

<table>
<thead>
<tr>
<th>Driver class</th>
<th>Driver</th>
<th>Tool</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Products / Development</strong></td>
<td>Main production process</td>
<td>Milkrun</td>
<td>SCM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Just in Time</td>
<td>SCM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sales, Inventory, Operations Planning</td>
<td>SCM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strategic planning</td>
<td>CF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change management</td>
<td>CF</td>
</tr>
<tr>
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