

## LITERATURE REVIEW OF EXISTING EVALUATION METHODS IN THE CONTEXT OF CHANGEABILITY

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### 1. Introduction

Conditioned by a multiplicity of disturbances in a production system it is crucial that the system can be adapted for unexpected occurrences. As a result many companies endeavour to create adaptable shop floors. Indeed the changeability of a system depends on numerous factors and the regarded system itself. Without an evaluation method it is not possible to show the degree of its changeability or changeability potentialities in a comprehensible way. In recent decades a multiplicity of evaluation methods were developed, nevertheless, those methods are used little or not at all in the automotive industry. Hence, this paper should give a best possible holistic overview about existing methods for determining changeability and to show their strengths and weaknesses. In general three main topics can be differentiated (Figure 1): On the one hand there are methods dealing primary with creative/constructive evaluations. The second group of methods evaluates monetary aspects and the last group pursues a holistic evaluation by combining the two aforementioned main topics in one method. Afterwards the summarized weaknesses and as a result of them research potentialities of existing methods will be shown.

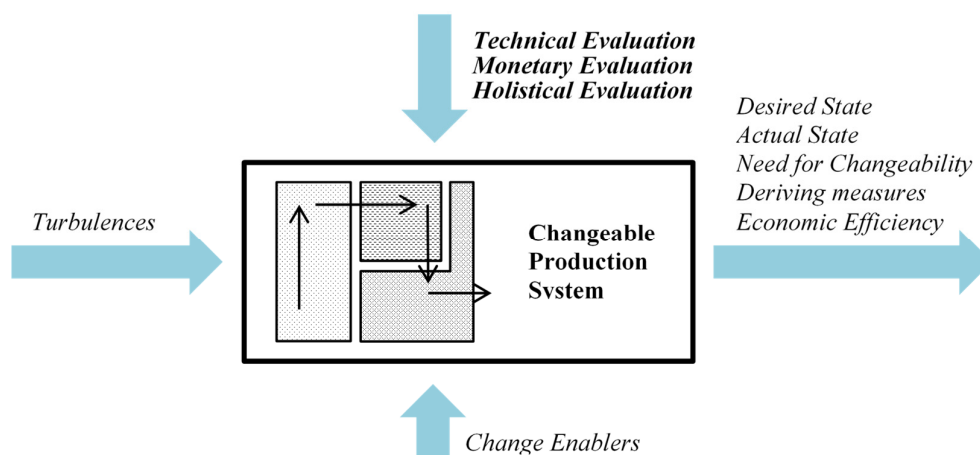


Figure 1. Evaluation of changeable production systems

Based on the results of the literature review, an approach of a new method for the evaluation of changeability will be introduced which purses the goal to be scalable regarding the level of detail and also to be applicable in the industry. This new method based on the approach of multi-criteria evaluation.

## 2. Changeable production systems

In recent decades a change in end-consumer behaviour is observable. Consumers want new products in ever shorter intervals with higher individuality at the same time. This trend is especially visible in electronic devices but also expands to other industries. Additionally unforeseeable sales fluctuations caused by economic depressions and governmental regulations are added which leads Original Equipment Manufacturer (OEM) responding to these changes to meet customer needs for saving at least the company's market share and to prevail against the competing companies. An approach to respond to the individualisation of the market is to increase the product variance [Daimler AG 2014]. To still stay efficient, economical and to respond to unforeseeable factors (so-called turbulences) a change in production towards changeable production systems needs to take place.

### 2.1 Definition changeability

As noted earlier, a production system is exposed to external interferences which exert pressure for change on the production system in the form of change drivers [Wiendahl et al. 2005]. As soon as the pressure for change reaches its maximum-limit and the company asks for change, design of change enables the possibility to adjust a system reactively or even proactively [Nyhuis 2008]. Thereby changeability is understood as a shift of flexibility corridors in a positive or negative direction without already charging this flexibility [Zäh et al. 2005]. That differentiates changeability from flexibility because flexibility is already implemented in existing system. From an economic point of view the idea of changeability is to first generate costs when the adaptations will be really necessary. Therefore concerning the pressure of change flexibility should be exhausted first before bringing changeability into action [Nyhuis 2010]. This definition of changeability has been established within the International Academy for Production Engineering (CIRP) academic and industrial community [EIMaraghy 2005]. The community of product design are concerning themselves also a lot with this topic but the definitions are more wide ranging [Jaratt et al. 2010]. Summarizing of different definitions a product should be "designed so that the product can be updated to meet future needs" [Barber et al. 1999].

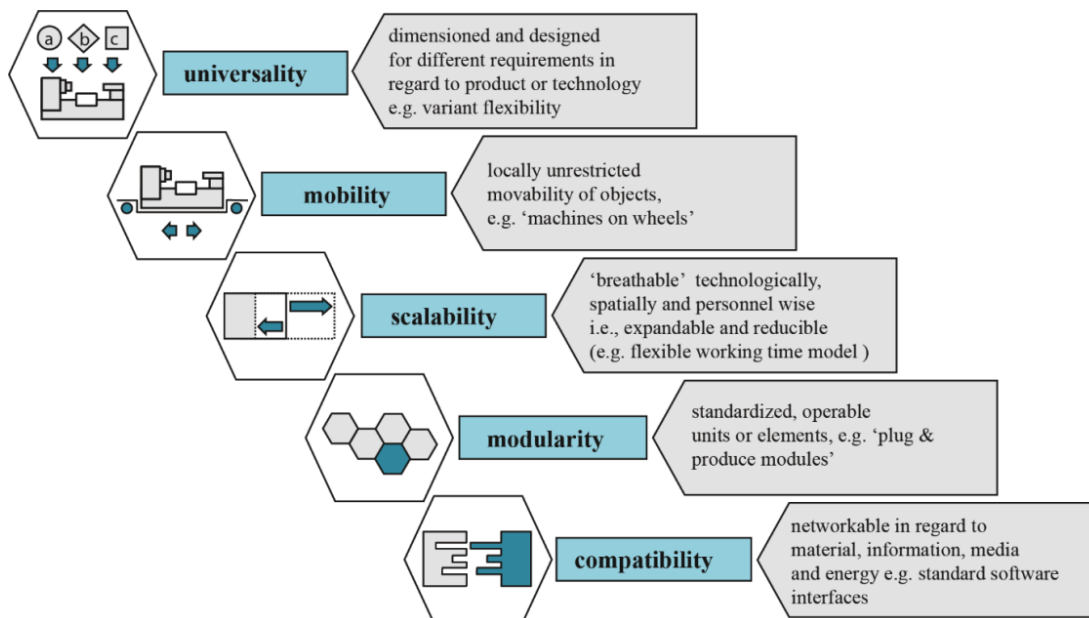


Figure 2. The five primary change enablers [Wiendahl et al. 2015]

## 2.2 Change enablers

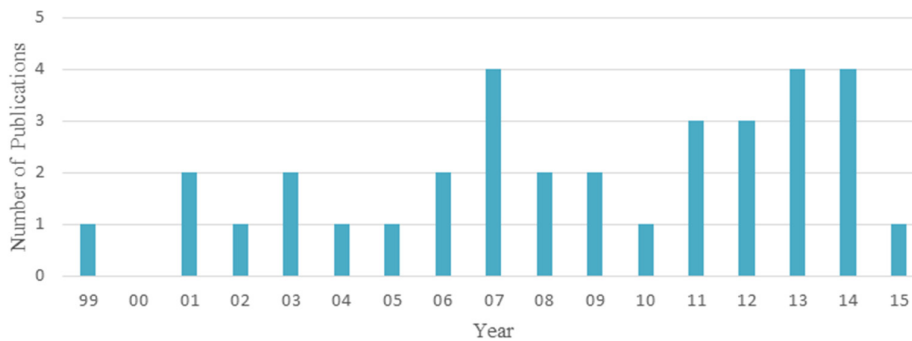
For a system's real-time response to turbulences the ability to respond is a key factor. Through integration of change enablers into a system it is possible to achieve the ability to respond [Nyhuis 2008]. At the hand of previous papers five primary change enablers were extracted: Universality, Modularity, Scalability, Compatibility and Mobility [Hernández 2003], [Wiendahl et al. 2007] (Figure 2). Rauch and Heger named Neutrality as a superior enabler which makes the five enablers possible in the first place. Thereby the characteristics of the change enablers define a system's degree of changeability [Heger 2007], [Rauch 2013].

## 3. Evaluation - Methods for changeability

See that change enablers are not absolute but rather possess a scope of discretion it is important to put the changeability in the context of the use case and to adapt accordingly. A comprehensible classification has to be applied for determining and changing a system's changeability. Furthermore the proper degree of a system's changeability is neither comprehensible nor generatable without an appropriate classification. As a result a range of methods for the evaluation of changeable systems have been developed which will be specified in the following subchapters.

### 3.1 Overview of previous work

The aim of the literature research was to depict a holistic image about previous methods or basic approaches which focus the evaluation of changeability in manufacturing systems. Therefore scientific databases, conference proceedings, libraries and sources of already known literature were examined. Literature which have the focus on subtopics of changeability like reconfigurability or flexibility are only considered if they are in a direct context of changeability. For this topic 67 sources were detected and after a first filtering of the results the number of sources which are qualified for this paper is reduced to 34. Thereby it is observable that since 1999 the number of publications increased by tendency and reached its climax in year 2013/2014 (Figure 3). In the year 2015 a reverse trend is noticeable compared to the previous years but it could also be explained as a temporary fluctuation like in the year 2010.



**Figure 3. Overview publication period**

The methods can be divided in three areas. 35% of the methods deal with the evaluation of changeability among technical aspects. Hernández for example uses scenario management for future factory scenarios which shall discover the need for change [Hernández 2003]. 27% of the literature focuses the monetary evaluation of changeability. Thereby among economic aspects an existing or already planned system will be evaluated like in Möller's method which evaluates systems on the basis of the Real Options Theory [Möller 2008]. The third area (38%) wants to evaluate systems in a holistic way meaning technical as well as monetary. For this kind of methods the methods of Hegers or Hees et al. have to be mentioned [Hegers 2007], [Hees et al. 2013]. Most of these methods are located in the Production Technology.

Remarkable is that the majority of these methods pursue a generic approach or are applicable specifically on one system like intralogistics [Nopper 2011] and nearly all evaluation methods, found in research

literature, were developed in Germany. But most of them (or parts of them in papers) were discussed on international conferences or cited in papers reviewed by international conferences.

### 3.2 Methods of changeability for constructive/design evaluation

35 % of existing methods handle with technical aspects of changeability. Here some evaluation methods have more the focus on assessing the existing changeability of a system [Heinecker 2006], [Nyhuis et al. 2013]. Other methods also detect the existing changeability but want to show up primary the need of changeability where they identify a target state and compare it with the actual state [Förster 1999], [Dürschmidt 2001], [Hernández 2003], [Klemke 2009], [Löffler 2011], [Klemke et al. 2012], [Albrecht et al. 2014], [Neumann et al. 2014], [Velkova 2014]. Table 1 presents the different methods compared by using an evaluation catalogue. Here the results should give the reader a rough distinction, characteristics or priorities are highlighted and compared to the other methods. It is assumed that the evaluation criteria are self-explanatory without the criteria scalability. Scalability describes the possibility to adapt the "effort to use the evaluation method" by simultaneous achieving usefull and detail - adapted results.

**Table 1. Comparison of technical evaluation methods**

	Albrecht, F. et al. 2014	Dürschmidt, S. 2001	Förster, T. 1999	Heinecker, M. 2006	Hernández Morales, R. 2003	Klemke, T. 2012	Klemke, T. et al. 2009	Löffler, C. 2011	Neumann, M. et al. 2014	Nyhuis, P. et al. 2013	Schuh, G. et al. 2012	Velkova, J. 2014
Qualitative Evaluation	◐	◑	◑	○	◑	◑	○	◑	◑	●	○	●
Quantitative Evaluation	◑	◐	◑	●	◐	◑	●	◑	◐	○	●	○
Considering the Need of Changeability	◑	○	◑	○	◑	●	◑	◑	◑	◑	○	◑
Scalability	◐	○	◑	○	◑	◑	◑	◑	◑	○	◑	◑
Usability	◐	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	●
Deriving Measures	◑	◑	●	○	◑	◑	◑	◑	●	○	◑	◑
Quality of the Results	◑	◑	◑	◑	◑	◑	◑	◑	X	◑	●	◑

Hernández adapts the methodology of scenario management on the topic of factory planning. Therefore future scenarios are created by influencing factors, which are followed evaluated in the width and depth of changeability. The changeability width shows how "strong" or "weak" the detected scenarios influence the entire factory. The depth is the difference between the actual state of changeability and the requirements of changeability on the basis of the change enablers. It should be assessed as positive that by determining the width of changeability the impact of changes on micro-level to the entire system is taken into account. To evaluate the depth of changeability a reference is made to the understanding and the imagination of the user and no quantitative methodology is suggested to generate the required changeability. A quantitative parameter to implement change enablers to the system is not a part of this method [Hernández 2003].

The method of Klemke et al. consists of two submethods, "changeability monitoring" and "changeability analysis". The core of the submethod "changeability monitoring" is derived from the value stream analysis and is called "change graphic". It is used to identify the changeability requirements of a system. "Changeability analysis", the second part of the method, has the duty to satisfy the previously detected mutability requirements. Again the "change graphic" is in focus, but this time also on second process

level. At the end of the method the results are verified by a changeability-measuring-consideration whether the present changeability is sufficient or not. The changeability is regarded as sufficient if a necessary adjustment is possible within the available period [Klemke et al. 2009].

Velkova has the focus not only on the technical point of view but evaluates the three dimensions of strategy, structure and culture. Therefore five steps have been developed with the aim of deriving action steps to improve the changeability of the system. Outstanding is that primary changeability factors are taken into account, which are categorized as change enablers, change constraints or change driver in combination with one of the factors mentioned before. This methodology is very user-friendly and scalable in its application, however, there is a risk for a too subjective evaluation result [Velkova 2014].

### 3.3 Methods of changeability for monetary evaluation

Some methods in literature have the focus on evaluating changeability purely monetary. This is justified, among other things, because the economy is the overarching goal in a company and therefore also the assessment should be structured like that [Möller 2007]. In Table 2, these methods are compared. Here a distinction is made between a static future or a dynamic one. Some evaluation methods have the focus on one possible scenario for the future and assesses it. With a dynamic future several scenarios for the future are possible or an ongoing change process will be assessed. Transferability describes if the method is very context - specific for one system or easy to use for other topic area/production layers.

The methods of Sesterhenn and Horváth et al. build, similar to Hernández, on future scenarios. Here Sesterhenn has the goal to generate an "optimal" production system by taking the life cycle into account, whereas Horváth et al. however place a monetary value if at selected periods a change from economic point of view makes sense. Otherwise the system remains unchanged for the regarded time period. The probability of change is one of the main values [Sesterhenn 2003], [Horváth et al. 2010].

**Table 2. Comparison of monetary evaluation methods**

	Witte, K.-W. et al. 2013	Sesterhenn, M. 2003	Briel, R. 2002	Möller, N. 2008	Horváth, P.; Urban, G. 2010	Nopper, J. R. 2011	Blumenau, J.-C. 2005	Sudhoff, W. 2008	Janorschke, B.; Probst, U. 2009
Static Future (one Scenario)	○	●	●	○	○	○	○	●	○
Dynamic Future	●	●	○	●	●	●	●	○	○
Transferability	●	●	●	◐	●	◐	◐	◐	◐
Usability	◐	◐	◐	◐	◐	◐	◐	◐	◐
Quality of the Results	◐	◐	◐	◐	●	◐	◐	◐	◐

- Criterion total fulfilled
- ◐ Criterion mainly fulfilled
- ◑ Criterion halfway fulfilled
- ◒ Criterion partially fulfilled
- Criterion not fulfilled / not considered
- X Evaluation not possible

In summary it can be said that the complexity and the effort resulting from the complexity of monetary evaluation methods increases exponentially when several potential changes are taken into account and the size of a production system rises. The effort is shown for example in the procurement of indicators, which are often difficult to determine. If these, however, are only estimated, the quality of results is reduced, which raises the question whether the benefit of the methods justify the effort by using them.

### 3.4 Methods of changeability for holistically evaluation

The majority of existing methods have the goal to evaluate a systems holistically - that is both technical considering viewpoints, as well as in monetary terms. Table 3 compares the methods for holistic

evaluation of changeability and demonstrates the strengths and weaknesses of each method. Afterwards, three methods are introduced in detail.

**Table 3. Comparison of holistic evaluation methods**

	Hees, A; Backhaus, J.; et al. 2012	Drabow, G. 2006	Heger, C. L. 2007	Dohms, R. 2001	Heine, F. 2015	Zaeh, M. F.; Reinhart, G. et al. 2011	Wiendahl, H.-P.; ElMaraghy, H. A. et al. 2007	Silm W. et al. 2013	Lunge, M. 2007	Keijzer, W. C. 2007 (exception)	Meyer-Schwickerath, B. et al. 2013	Albrecht, F.; Faatz, L. et al. 2014	Schul, G. et al. 2004
Qualitative Evaluation													
Quantitative Evaluation													
Considering the Need of Changeability				X									
Scalability							X						
Usability							X						
Static Future (one Scenario)													
Dynamic Future													
Transferability							X						
Deriving Measures							X						
Quality of the Results							X						

Dohms has developed a method to identify and evaluate structure-related adjustment requirements in a production system. His method is divided in the four areas analysis, evaluation, decision, and design. Within these ranges, a big variety of different methods are used, which can not be mentioned all of them at this point. The strength of the method is the detection of controlling parameters after prioritizing the company's goals. The company's goals contain goal preferences and strategies of the considered company. One part of the method handle with the measure of structural adjustment. However, Dohms shows a too generic approach and it is not described properly how to implement change enablers into a production system [Dohms 2001].

Drabow's method for a holistic evaluation of changeable manufacturing systems based on the method of cost-benefit analysis. The bottom-up strategy is used for evaluation. The five primary change enablers serve as the target system, which are detailed in further specification criteria. Here there is a specific rating scale for each change enabler. To take account of the costs a link between the Changeability Index and the Cost of Change is generated. Although the right level of mutability be considered within the requirement profile, but unfortunately there is no information how the target image can be determined [Drabow 2006].

Meyer-Schwickerath et al. have the primary goal to increase the changeability of small and medium sized enterprises (SMEs). For this, the method of scenario management is used. Of particular interest is

the fact that the observation focus is narrowed down even before starting the evaluation and changing objects are identified within this. With a target-actual comparison the need for change is derived. Specific evaluation parameters are not directly addressed, but it is mentioned that the evaluation can be done by a circle of experts. Therefore, some approaches can be taken and adapted, but a concrete applicability of the whole method is uncertain [Meyer-Schwickerath et al. 2013].

### **3.5 Deficits existing evaluation methods**

The literature review showed that good and interesting approaches within existing evaluation methods exist. However, most of technical and holistic methods are generic in nature and a concrete applicability seems to be difficult. Other methods evaluate a system context-specific, such as a picking system [Heine 2015], which complicates a transferability to other problems or other production layers. Purely monetary valuation methods are easier to handle in its transferability to other issues. However, the effort of applying the method to the results is very high. In addition, the effort increases exponentially when considering multiple influence parameters and change variables. The reason for a generic or very specific point of view can be found in the multi-dimensional of changeability, where several target variables are important and therefore a concretization of the methods is very challenging. In existing methods the correlations and the partial overlap of the change enabler definitions are not or insufficiently considered. Therefore, a research potential can be indicated by disregarding the primary change enablers as neutral, but rather to bring them in a common context and show their dependencies. Another aspect is the right degree of changeability. This is interpreted differently. Methods like Hernández , several holistic evaluation methods as well as a lot of monetary evaluation methods (see Table 2) determining the degree of changeability through future scenarios [Wiendahl et al. 2007], [Sihn et al. 2013], [Meyer-Schwickerath et al. 2013], [Albrecht et al. 2014]. Others have the goal to implement change enablers in a system without determining the degree of change enablers and the resulting changeability or deducing measures [Heinecker 2006], [Nyhuis 2013]. As a result of the consideration of existing methodologies to assess the changeability of a system in the automotive sector, a concrete and manageable applicability of an existing method is only conditionally possible. However, interesting aspects can be implemented in a new method for the holistic evaluation and design of a production system in the automotive industry.

## **4. Approach to the development of a holistic evaluation method**

In order to satisfy the topic of evaluating changeable production systems, minimizing weaknesses of existing methods, using the benefits of strengths and to ensure applicability, a new evaluation method will be developed (Figure 4) and the idea of it will be introduced here shortly. This method is based on the principle of multi-criteria evaluation and has its focus on the automotive industry, but also should be adaptable to other industries.

As a first step, a target image of changeability is set up in the context of the considered company. This target image is serving as framework of the assessment and has the goal to reduce the theoretically possible ideal of changeability, towards a defined structure of changeability, which fulfills the requirements of the company. Therefore factors such as product range, product cycles, duration of the planning, ... helping to determine the specific target image. Here, the right balance is crucial in order not to affect adversely the changeability for the future, but to set clearly defined boundaries, which help to reduce complexity and improve the usability of the method. The idea of the method is that a considered system consists of subsystems, which have a varied degree of correlation to each other and it has a positive effect on the changeability of the entire system by increasing the changeability of a subsystem. Therefore, these subsystems are to be detected using the new approach of Prioritization Indicators which consist of the three factors dependence of the subsystems, the effort to adapt a subsystem and the effectiveness, that means how a maximum of change within the target image effects on the changeability to change the entire system. The evaluation criteria are the primary change enablers, and existing correlations and definition overlaps of them are taken into account. It is necessary to examine how the change enablers express themselves in different layers or how they are weighted. The three prioritization parameters are brought in relation to each other by multi-criteria evaluation. After determining the Prioritization Indicators each subsystem has a unique parameter. With this on the one hand a change order of the subsystems can be determined to increase the changeability of the whole

system. But also on the other hand a limit within each subsystem can be determined, where the necessary of change is in focus. Also, the method helps to detect the limit when the benefits of changeability in economic terms are no longer outweigh and therefore no higher degree of change enablers should be implemented in a system.

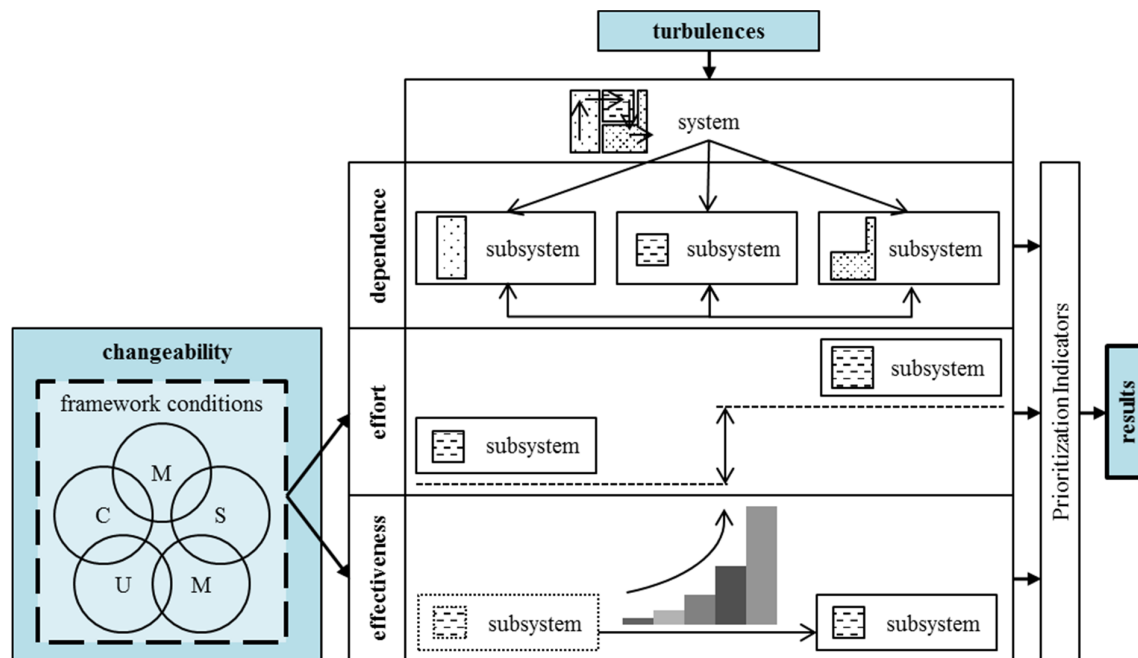


Figure 4. Structure of new evaluation approach

Generally the method should be scalable in its application depth to have a manageable balance between costs and benefit. This scalability is implemented by splitting the entire system into subsystems and by adapting the level of detail. So both operations planning processes as well as concrete questions in the planning process can be considered.

## 5. Conclusion and outlook

In this paper, a holistic overview of existing methods to evaluate the changeability was conveyed. These were set against by evaluation criteria and compared to each other. It was noticeable that there is a generic approach or specifically limitation to a subsaspect of a system. This complicates a concrete applicability. In addition, dependencies of subsystems have been neglected, also the overlapping or correlations of change enablers. These results of the study led to research potentials and showed the need for a new evaluation method which takes strengths of existing methods into account, but also consider the weaknesses of the methods. Based on the results of the literature review, the paper presented a new approach to evaluate the changeability of a system. It measures subsystems by Prioritization Indicators essentially, which defines an acting order how subsystems be adjusted. But also set a limit to show at what point an adjustment of a system by implementing change enablers seems not useful anymore. In future work it is necessary to concretize the evaluation by prioritizing metrics and validate it on the basis of industry applications.

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