An Approach to Assess Engineering Change Effort Retrospectively Utilizing Past Engineering Change Information

Niklas Kattner[1](✉), Eldar Shakirov[2], and Udo Lindemann[1]

[1] Technical University of Munich, Munich, Germany
niklas.kattner@tum.de

[2] Skolkovo Institute of Science and Technology (Skoltech), Moscow, Russia

Abstract. The competitiveness of companies is nowadays highly dependent on an efficient product development. Shorter time to market, increased competition as well as accelerated market dynamics can be handled well by a continuous improvement in development efficiency. Hence, improving the development performance can have a big impact on the time to market. However, an increasing number of resources must be assigned to the management of engineering changes. The management of changes strongly influences the resources available for the actual design process. Furthermore, the increasing complexity of technical systems as well as the organization affects the engineering change situation and further induces change complexity. This paper therefore introduces an approach to retrospectively assess engineering change information to identify areas for reducing the change workload. It therefore introduces a procedure to guide users through the process of the assessment. In addition, it suggests indicators to evaluate the change situation regarding the induced workload. Finally, the approach is applied in a use case to investigate an engineering change data set.

Keywords: Engineering change management · Structural complexity management · Engineering change assessment

1 Introduction and Background

In recent years, the complexity of modern technical systems increased rapidly [1]. Hence, the organization of product development tasks becomes more complex as well and the effort to collaborate and cooperate increases within the company. As a result, the resources in form of people's minds behind the actual development and maintenance of products are increasingly valuable for the company, since the projects are more demanding due to complexity and scope. This requires a lot of man power for meetings, improvements, iterations and testing. The actual task of engineering by creating technical products and systems is pushed into the background. Hence, a lot of potential for improving the product development task – and the actual development performance – is in the optimization of tasks and cooperation influencing the product development

Published by Springer Nature Switzerland AG 2019
C. Fortin et al. (Eds.): PLM 2019, IFIP AICT 565, pp. 223–232, 2019.
https://doi.org/10.1007/978-3-030-42250-9_21

activities [2]. One major consumer for product development resources is the handling of engineering changes. These changes are usually defined as changes to parts, drawings or any other development artefact, after these artefacts have been released [c.f. 3, 4]. They are usually carried out to improve products, adapt them to new requirements and needs or to correct errors. Studies have shown that the share of the overall development capacity required to handle changes is significant. [5, 7] give a share of the change work in the total development capacity of 30–50%, partly up to 70%. [6] indicate that about 30% of the work load for reworking and implementation of additional functions is due to changes. Hence, improving the handling of engineering change management by reducing the change effort promises to be a big lever in the improvement of the overall resource usage. However, literature lack research about how to systematically investigate the efforts in engineering change management [3]. The paper therefore introduces an approach to utilize past engineering change information to retrospectively assess effort indicators for a given technical system. Hence, Sect. 2 outlines the methodology as well as the shortcomings and the goal of the paper. Section 3 introduces an initial set of effort indicators. Section 4 introduces the method and describes the systematic procedure. Section 5 briefly pictures the application of the method in a use case. In Sect. 6, the results of the application are discussed as well as the content of the paper is summarized.

2 Methodology and Shortcomings

The research is based on the Design Research Mythology [8]. Hence, a profound research clarification was conducted in the beginning of the study to refine the objective of assessing change information retrospectively. In the following step - the descriptive study 1 - a literate review revealed the current state of the art regarding retrospective change data analysis and performance measures in engineering change management. An overview of current research can be found in [c.f. 9, 10]. In this paper, the focus is on the prescriptive study, which embraces the development of a methodology to improve change handling and the overall engineering design process by assessing the technical change information retrospectively. Thus the following hypothesis defines the research of this paper: The assessment of engineering change information retrospectively helps to better understand the characteristics of high workload in engineering change management. Hence, by uncovering the root characteristics of high change effort, proactive measures can help to reduce the overall use of capacity for change management in engineering design. In Sects. 2.1, 2.2 and 2.3 we discuss shortcomings to underline the introduced hypothesis by emphasizing potential to improve engineering design. The shortcomings are derived from current state of the art in research [3, 9].

2.1 Shortcoming 1: Defining Engineering Change Effort

As discussed above, handling engineering changes has a fundamental impact on design performance, since it uses resources not available for the design task. As a result, engineering changes can be the origin of performance lacks, shortcomings in the development progress or cost drivers for companies. Since engineering changes are more a rule than the exception in companies and are often necessary to adapt to new requirements, a broader understanding of the causes of engineering change effort will allow for improving the change handling itself. Hence, a more granular approach to uncover effort indicators describing change effort to precisely understand, address and improve the use of resources for either the change handling itself or the general engineering design task is necessary.

2.2 Shortcoming 2: Methodical Approach for the Systematic Assessment of Change Effort

Many approaches in engineering change management address the actual process of engineering changes handling beginning from the first occurrence, to the evaluation of the change effects to the implementation. Furthermore, many retrospective methods focus on the support of the actual change handling [3, 9]. Therefore, a lack of methods to learn based on past change information not for the process itself, but for the knowledge gain to reduce the effort in a systematical way can help to maintain an efficient engineering change management. Hence, a methodical approach as a guidance for a continuous learning is introduced in the following.

2.3 Shortcoming 3: Utilizing Past Change Information to Investigate Drivers for Engineering Change Effort

In companies the management often ends when the change is closed, and the implementation was successful – or the change request was rejected. Nevertheless, a systematic learning and monitoring of changes regarding their capacity and resource use is crucial when it comes to an efficient development process. Hence, simplifying the process of learning from past engineering changes by decreasing the resistance to apply assessment and monitoring methods can leverage the acceptance of such approaches. Therefore, a method which adapts to the company's situation and either allows to qualitative assess past engineering change information or process change data to observe the resource use will be beneficial for industry. Since many companies must document many change relevant data, an automated assessment of change data to reveal change efforts can further lower the barrier to investigate the changes retrospectively.

2.4 Focus of the Paper

This paper therefore introduces a method for a systematic assessment of engineering change information to uncover, assess and process past engineering changes regarding the effort and its resource consumption. This helps to identify major performance lacks in engineering change management and therefore in engineering design, to proactively improve engineering design and therefore free resources for the actual development of the technical system. This can be achieved through better understanding of the origins of resource binding for the technical system.

To give an overview of the methodology, the paper furthermore emphasizes on the assessment of past engineering change data. Hence, a limited set of structural measures are introduced as an example for the calculation of the change effort indices. The actual calculation is mainly based on the approach of structural assessment [11] with engineering change data retrospectively.

3 What Induces Effort in Engineering Change Management?

The shortcomings outlined that there is a lack of research in engineering change management regarding the identification and observation of effort and feasible indicators. In addition, the actual identification and investigation of the root causes of effort drivers in engineering change management is lacking in current research. This paper thus introduces an approach to define effort in engineering change management utilizing structural assessment approaches. A broader scope to apply the investigation within the collaboration with the manufacturing department is planned for a future assessment.

To ensure a broad applicability of the indicators, the objective of deriving these indicators were to use only the most common information usually available in companies about engineering changes. The change number, the persons involved in the change handling as well as the artefacts under change are therefore used for evaluating the effort induced by engineering changes within a predefined scope of a technical system. By utilizing this structural information about the engineering change situation, interrelations and its strength, indirect dependencies and the degree of networking can be used to assess the technical system. Since the approach uses engineering change information, the assessed data is always based on actual shortcomings, technical improvement activities and cost reduction projects. Hence, the interrelations are defined by objectively generated information, i.e. the documentation of engineering changes or the retrospective reflection of experience, instead of a proactive approach with anticipation and hypothesis.

Table 1. Initial set of measures to assess engineering change effort

	Measure	Explanation	Based on
Product-based effort measures	*Frequency*	Number of Change requests per Module	[13]
	Network factor	Strength of bonding of the module (number of occurrences with other modules)	[13]
	Centrality	Centrality of the Module within the product structure	[13]
Organization-based effort measures	*Involved people*	Number of involved people	[13]
	Collaboration resistance	Collaboration Resistance per Module – average hierarchical distance between all involved people	[14]
	Network factor	Average network factor of all involved people	[13]

Reflecting the origin and driver for effort in engineering change management, there are three major categories – product, process, and organization. Either the effort can be induced and generated by the artifact under change itself – product-based change effort. Also, the effort for handling engineering changes can emerge from the organization and its entities handling the change – organization-based change effort. A third driver for change effort is the actual process management. However, since literature provide a lot of research in the reactive phase – either in the form of change processes itself or supporting methods – the third category is excluded from further investigation.

Hence, there are two groups of measures defined to assess past engineering change information regarding the effort for changes management. The groups each include three initial measures which allow for a structural assessment and are meaningful for the overall effort situation of an engineering change to an engineering artifact (see Table 1).

4 Assessing Engineering Change Information

To create a more structured approach to remedy the lack of understanding regarding the origin of resource usage for conducting engineering changes, a methodical approach is introduced guiding through the steps to create an understanding of the change situation. Thus, engineering change information from past changes – either in the form of quantitative and formalized data or in the form of informalized knowledge – is used to create a basis to retrospectively assess the technical system regarding the induced change effort. To do so, the methodical approach consists of 3 major phases depicting 5 independent steps (see Fig. 1). It is built up as a circular procedure to emphasis the recurring character of the methodology. Since the engineering change situation in companies usually is a dynamic environment, the method has to represent this character by underlining the importance of an iterative application. We assume, that by applying the method, or at least certain steps, the information is kept up to date. This ensures that the information about effort always adapts to the company's individual constraints. The methodology depicts the three major phases preparation, assessment and support.

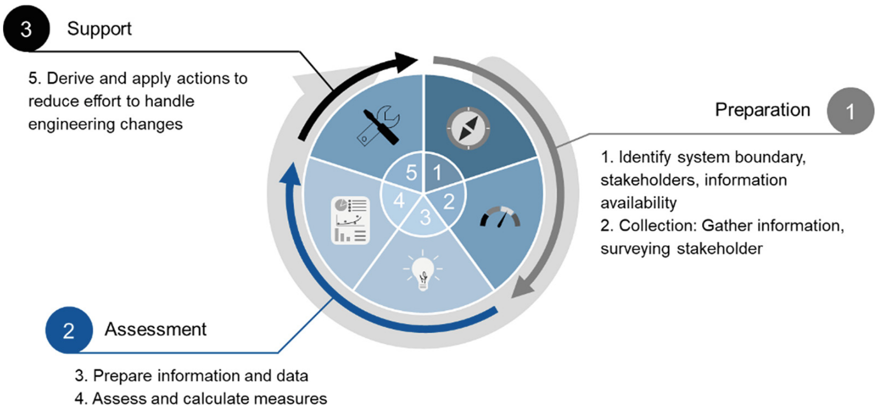

Fig. 1. Method to retrospectively assess change effort

The 3 phases of the method can be applied individually without the necessity to start with the first. However, by doing so, the certain pre-checks have to be finished to ensure that all information is available for the phase to successfully accomplish.

4.1 Preparation

In the preparation step, a change management team needs to identify and gather all information necessary to conduct the analysis. Therefore, the first step 1 of the procedure includes the identification and definition of a viable system boundary. It is important to define the scope of the assessment at the beginning – e.g. whether it is just a small assembly of a product, i.e. constraint by the engineering unit – or the investigation of a whole product or project. However, the scope of this assessment can be limited by the resources available to apply the methodology as well as the type of information available. Data driven assessment allows for a bigger scope as the analysis can be automated. The second step of the methodology includes the actual gathering of information. Dependent on the in step 1 identified situation, the information is either available in a formalized, explicit way in the form of engineering change documentation or must be collected by questionnaires to document the informalized, implicit knowledge of the people. This paper describes the situation of a situation within a company, where engineering change data is available. To prepare the assessment step, the information therefore has to be derived from a database. To do so, the respective people have to be identified and all necessary approvals for the assessment must be signed. Furthermore, a data preparation is necessary.

4.2 Assessment Phase

The assessment phase focuses on the evaluation of the previously gathered information. Depending on the information available, it either allows for an automatic calculation of the engineering change data or the manually assessment of the measures using questionnaires.

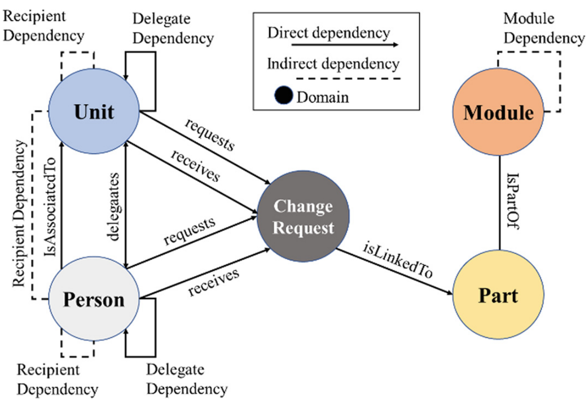

Fig. 2. Meta model of the engineering change data

Since many companies have formalized and documented information about engineering change handling, the method also considers the automatic calculation of the effort measures. Hence a meta model is introduced derived on the structure of existing literature to the main artefacts of engineering change managements and its interrelation [c.f. 3]. The metamodel was furthermore refined with the logics derived from engineering change databases from industry [12]. The overall objective of the meta model was to include as little engineering change relevant objects as possible but still allow for a usable analysis of the change effort measures.

By reducing the number of objects relevant in engineering change management, the approach is easier to apply in a variety of different companies by increasing the likelihood of the availability of all necessary information. The simplified metamodel can be seen in Fig. 2.

The meta model defines the interrelations between the information used in this method and therefore serves as the basis for the calculation of the measures. Based on this meta model, the use case in Sect. 5 introduces the analysis of the network regarding the set of structural engineering change effort measures.

4.3 Support

The support phase finally helps to address the effort indicator to improve the overall engineering change situation. Hence, either a catalog of change drivers and respective counter measures or methods to improve collaboration or reduce organizational dependencies must be considered. Due to the previously identified information, a network of stakeholder is already available. This stakeholder information is used to identify key engineers for a workshop-based processing and assessment of the information.

5 Use Case

The following use case introduces the application of the method with focus on the calculation of the indicators by using an engineering change data set from a big company in the automotive sector. The analysis was applied to data set of 711 engineering change requests – constrained by focusing on one engineering design unit. Furthermore, the data set was limited by the time period under consideration of six months to further reduce the amount of data to be calculated. A data preparation step was conducted to ensure the structural assessment can be conducted – e.g. removing incomplete information, translate data types. As a demonstrator Soley Studio was used to conduct the structural assessment. The software enables users to calculate and handle structural data and hence, allows for graph analysis. The case mainly focusses on phase two of the methodology, hence the focus will be on the actual data assessment. Therefore, the data gathering won't be discussed. In addition, the further use of the information as well as the usage is just explained initially.

In the first step, the graph network is built by importing the engineering change data into the software demonstrator. The tool then applied previously defined rules based on the meta model to generate the concerning elements (EC, persons and artefacts – in this case modules) and its interrelations to create the structural network of the data.

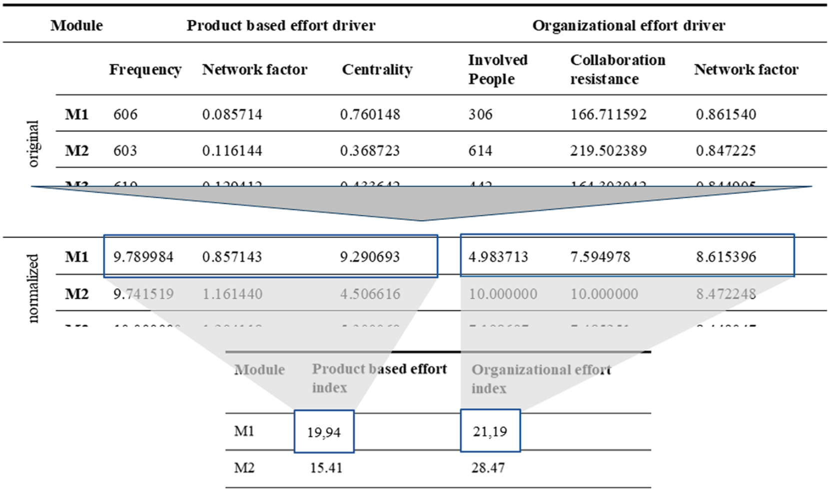

Fig. 3. Calculation of the effort index

The network allows for the calculation of the in Sect. 3 introduced measures based on the in Sect. 4.2 introduced, simplified meta model for the assessment of the change effort. Hence for each module of the technical system the measures are calculated. Since the measures are derived from network analysis, first the original calculations are conducted for each module of the system under consideration. In the case of this example, the system comprises 103 modules.

Figure 3 shows an excerpt of the analysis results. The original calculations are then normalized, and the normalized indicators then serve to calculate a cumulated value for the product-based effort and the organizational effort. Hence, these indices allow for an estimation of the product and organizational characteristics and company specific properties on the engineering change effort. Based on these two indices, a portfolio is derived which enables a simplified, visually supported assessment of the modules regarding their respective effort indices (see Fig. 4). The portfolio allows for an easy comparison of the systems modules regarding their induced effort when changed during the development. To do so, the portfolio spans the organizational effort over the system effort. Thus, the portfolio supports the assessment of the effort drivers and allows to directly reveal measure categories to improve the change situation. For organization-based effort drivers, the improvement of collaboration, the people involved as well as the unit interrelations can be a leverage to reduce effort in change handling. For product-based effort drivers, the improvement of the product structure, the reduction of changes as well as the change propagation are viable starting points to release resources for engineering design by improving the change management. In summary, the portfolio is a first approach to quantify the change effort allocated to the technical artefacts of a system. This increases the transparency of resource usage and therefore is a basis for discussing and improving the engineering change management.

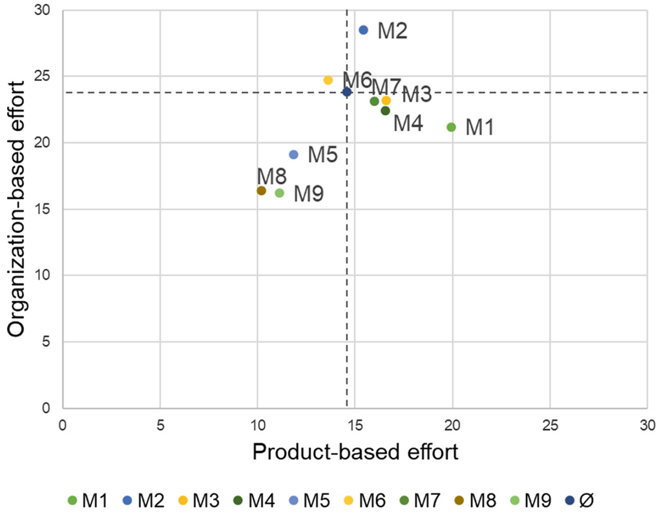

Fig. 4. Modules portfolio of engineering change effort

6 Conclusion and Summary

The paper gives an overview of a method to retrospectively assess engineering change information to investigate the effort induced by changes to the technical system and emphasizes how engineering change information can be used to improve design performance. This knowledge can then be used to either improve the resource usage by directly addressing causes of high effort or to evaluate the potential effort necessary to conduct changes to certain system artefacts. The paper showed that structural complexity measures can be applied to an engineering change dataset. Furthermore, the measures can reveal indicators for high engineering change effort retrospectively. Since the documentation of engineering changes vary in industry, the flexibility of the approach must be further investigated. In addition, the set of indicators is limited in this paper in 6 measures to reduce the effort for implementing the indicators in the software tool. However, an extension of indicators could allow for a more extensive investigation of either organizational induced effort or product induced effort. With the application of the method and the assessment of a data set, the resulting portfolio shows visually prepared information about the effort indices to characterize the system under consideration regarding the change effort. For future research, the focus is on a more in-depth application of the procedure. Hence, the measures must be applied to different types of change data. A weighting system for the individual effort values would allow for more flexible assessment of the information. Furthermore, a list of comprising actions to improve the change situation depending on the effort indicator's characteristics would allow for a focused measure to address the effort causes.

Acknowledgement. This work was supported by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) collaborative research centre 'Sonderforschungsbereich SFB 768 "Managing cycles in innovation processes – Integrated development of product-service-systems based on technical products". Furthermore, we thank the Soley GmbH for providing the data analytics tool.

References

1. Fricke, E., Schulz, A.P.: Design for changeability (DfC): principles to enable changes in systems throughout their entire lifecycle. Syst. Eng. **8**(4), 342–359 (2005)
2. Clark, K.B., Fujimoto, T.: Product Development Performance. Strategy, Organization, and Management in the World Auto Industry. Harvard Business School Press, Boston (1991)
3. Hamraz, B., Caldwell, N.H.M., Clarkson, P.J.: A holistic categorization framework for literature on engineering change management. Syst. Eng. **16**(4), 473–505 (2013). https://doi.org/10.1002/sys.21244
4. Jarratt, T.A.W., Eckert, C.M., Caldwell, N.H.M., Clarkson, P.J.: Engineering change: an overview and perspective on the literature. Res. Eng. Des. **22**(2), 103–124 (2011). https://doi.org/10.1007/s00163-010-0097-y
5. Lindemann, U., Reichwald, R. (eds.): Integriertes Änderungsmanagement. Springer, Heidelberg (1998). https://doi.org/10.1007/978-3-642-71957-8
6. Fricke, E., Gebhard, B., Negele, H., Igenbergs, E.: Coping with changes. causes, findings, and strategies. Syst. Eng. **3**(4), 169–179 (2000)
7. Maier, A., Langer, S.: Engineering change management report 2011. Survey results on causes and effects, current practice, problems, and strategies in Denmark (no. 17), Technical University of Denmark, DTU (2011)
8. Blessing, L.T.M., Chakrabarti, A.: DRM, a Design Research Methodology. Springer, London (2009). https://doi.org/10.1007/978-1-84882-587-1
9. Tale-Yazdi, A., Kattner, N., Becerril, L., Lindemann, U.: A literature review on approaches for the retrospective utilisation of data in engineering change management. In: 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), pp. 612–616. IEEE (2018)
10. Kattner, N., Wang, T., Lindemann, U.: Performance metrics in engineering change management - Key Performance Indicators and engineering change performance levels. In: 2016 International Conference on Industrial Engineering and Engineering Management, IEEM 2016, 4–7 December 2016, Bali, Indonesia, pp. 1180–1184. IEEE, Piscataway (2016)
11. Maurer, M.S., Lindemann, U.: Structural awareness in complex product design - the multiple-domain matrix. In: 9th International Design Structure Matrix Conference (2007)
12. VDA, 4965 (08/2009). ECM Recommendation Part 0 (ECM)
13. Biedermann, W.: A minimal set of network metrics for analysing mechatronic product concepts. Dissertation, Technische Universität München, München (2014)
14. Heimberger, N.: Strukturbasierte Koordinationsplanung in komplexen Entwicklungsprojekten. Ph.D. thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM) (2017)