21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

EXPERT BASED APPROACH TO ANALYSE AND INFLUENCE INDIRECT COST OF ENGINEERING CHANGES

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Abstract

Indirect cost of engineering changes represent increasing challenges for companies. Their high frequency and complex cost impacts makes it difficult to estimate and influence the cost outcomes. Currently direct cost (eg. changed material) are well mastered in industry, but indirect cost (e.g. engineering design, administration, testing, procurement) are not yet supported sufficiently. Early knowledge of amounts and effective measures to influence indirect costs can be crucial for the economic result on the market. Hence, fast and easy prediction and influence methods are needed in practice. The article describes an application-oriented approach to analyze systems behaviour of indirect cost based on expert estimation and weighted influence matrices. As multiple domains within the company at different times involve during change process, a flexible, customizable and open model structure is proposed for solution. This enables to represent the characteristics of company individual and change case-specific indirect costs. We also present a corresponding approach for company-specific derivation and application of indirect cost reduction measures.

Keywords: Indirect cost, Engineering change, Multi- / Cross- / Trans-disciplinary processes, Complexity, Systems Engineering (SE)

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 4: Design Methods and Tools, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

Development of customer-specific solutions are significant competitive advantage of many supplier companies in the automotive industry. To maintain this competitive advantage, suppliers must constantly follow the product changes made at the manufacturer level, i.e. make even changes to its own products. Only in this way, the changing requirements of the automobile manufacturers of purchased parts, components and modules can be met consistently. From a supplier perspective, such product changes represent manufacturer, i.e. customer-induced product changes. Customer-induced product changes are not predictable businesses and occur very often. „In today's customer-driven and dynamic markets, [engineering changes] […] cannot be avoided entirely; they are rather the rule than the exception […]." (Hamraz and Clarkson, 2015). A central importance therefore is to manage (analyse and influence) cost of product changes efficiently. Established design methods only partly support the cost-effective implementation of customer-induced changes. Existing methods to reduce costs can be applied only to a limited extent for the specific and heterogeneous types of product changes.

To fill this gap, an application-oriented **change process model** is presented in this article. It contributes to manage indirect cost of design changes, which were not easy be quantified and influenced by companies before. The change process model provides transparency regarding the causation and emergence of indirect cost of change for this reason in a first step and it shows the influence of the main cost drivers on activities in the change process and the disciplines involved.

Due to current non-transparent causation of indirect cost of change, so far no suitable measures for cost reduction can be efficiently derived. Based on the change process model and the analyses carried out, companies are enabled to systematically derive adequate company-specific measures to control indirect cost of changes. The change process model provides transparency on the systems-behaviour of indirect cost, and shows where and when measures for cost reduction can be applied.

2 DEFINITIONS AND RESEARCH FOCUS

Definition of "indirect cost of design change" used in this research include all cost associated to a change process to implement a product change from activities to provide a performance output necessary in this process. Indirect costs arise from change-induced activities in indirect domains. Indirect costs *y* of change *s* result from the sum of the product of times *t* necessary for the implementation of change activities *h* in indirect domains *j* involved in product change process and staff cost rates *k* of employees *m* that carry out activities:

$$y_s = \sum_{j=1}^{J} \left(t_{h,j} \times k_m\right) \tag{1}$$

Focus of this research are indirect cost of one specific change case. This includes all indirect costs that are directly consumed to implement a specific change. Effects like opportunity costs (Windheim and Krause, 2016) considering change case interactions or further effects were not examined here.

3 STATE OF THE ART

Complex nature of indirect costs makes it difficult and time consuming to determine the manifold effects and consequences (Friedl et al., 2013). Bottom-up methods like activity-based costing (Barfield, 1994) were improved to simplify their application and effort (Kaplan and Anderson, 2007; Baltzer and Zirkler, 2012). However, this development to "time-driven activity based costing" is not suitable for a quick estimation of indirect cost of change because of relative high effort in practice.

If the indirect cost of change is taken into account, in practice we can find representations like general or absolute cost values, overhead rates and (subjective) experts estimates (Gebhardt et al., 2016). For early stages in design and change situations, the field of indirect costs is currently at early research stage (Mörtl and Schmied, 2015). All established methods can not represent the system behaviour of indirect cost of engineering changes. Systems engineering approaches for cost management were previously

more focused on special cases, e.g. for statistical methods to enhance accuracy of cost estimates (Garvey et al., 2016).

International systems engineering standard works (Blanchard, 2009; Walden et al., 2015), on the one hand, highlighted the complexity of the indirect costs (e.g. for overhead costs, life cycle cost, etc.). But fast and easy analysis approaches that go beyond the consideration in form of percentage rates have not been found in international literature. Theoretical systems engineering consideration for cost management have shown to be capable of examining cost impacts of changes (Schmied et al., 2015). As indirect change costs show company- and case-specific behaviour (Gebhardt et al., 2016), an analysis method must be able to represent this core aspects. General findings on indirect costs from business- (Gleich and Marfleet, 2012) and engineering contexts (Ehrlenspiel et al., 2014), therefore, can be only partly adopted to company context and change case situations.

4 RESEARCH METHOD

This research employs expert estimation as method to derive data about systems behaviour of indirect cost. Weighted influence matrices are used to describe company- and case-specific indirect cost impacts. From systems engineering perspective we claim that indirect cost of engineering changes can be considered as a system that can be further divided into its elements. With hypothesis that cost behaviour at element level can be better assessed, and total behaviour is a set of company- and case-specific composition of respective elements, we assessed and improved our model with six companies. Expert estimation was chosen due to its fast and easy application an appropriate average accuracy of +- 20%. Influence matrices were chosen to be compatible with more powerful analysis instruments in complexity management on their facets on cost (Browning, 2016), visual options like strength based graphs (Lindemann et al., 2009) and process related structure aspects (Kreimeyer and Lindemann, 2011). The presented approach for analysis method in our research relies on the interactions of elements cost drivers, activities and roles in the change process. It will be referred as "change process model" in next chapters.

5 ANALYSING INDIRECT COST OF ENGINEERING CHANGES

5.1 Structure of change process model

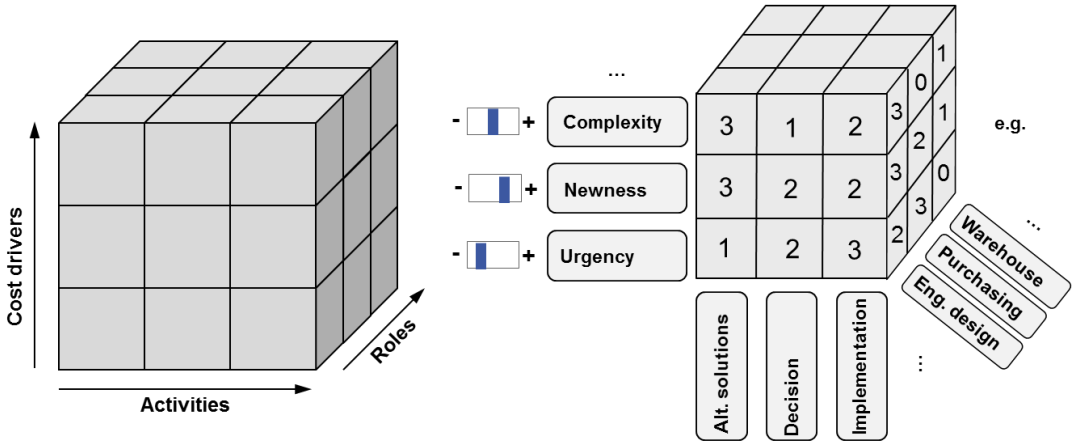

Figure 1. Structure of change process model

Figure 1 left shows overview total model of change process model with domains/elements:

- Cost driver (main influencing factors).
- Activities (process steps in change process).
- Roles (company departments, involved workers).

The change process model (simplified example, see Figure 1 right) includes the domains/elements cost drivers, (change process) activities and roles (e.g. company departments), whose interactions represent

system behavior and make indirect change cost transparent regarding to when, where and to what extend indirect cost incur, and to systematically apply cost reduction measures.

Cost drivers represent the input variables of the change process model by describing the specific case (classification of the change case on the basis of characteristics such as low, medium or high complexity) and show, which cost drivers are of particular importance for a company. This perspective is used to answer the questions, by what indirect change cost are caused and to what extent they incur.

Activities reflects the structure of typical company-specific process steps and make it clear what activities/process steps for the implementation of a specific change are required and to what extent. This perspective is used to answer the questions of when and where indirect change costs are incurred in the process of change.

Roles (e.g. company departments) include all disciplines involved in a change process typically. The goal is to present what roles to what extent are involved in a specific change process. This perspective is the answer to the question where, i.e. at what indirect company domains costs incur.

The understanding of the interactions of the three elements of cost drivers, activities and roles is crucial to establish (1) transparency (i.e. which, when, where, and to what amount are indirect cost of change) and (2) based on that derive targeted measures for control of indirect cost of change. The process model allows the change case-specific and company-specific design to analyze interactions of three elements. Therefore, the interactions and their influence strengths of these three elements must be raised first on the basis of expert workshops.

As shown in simplified example of Figure 1, this can be done by influence matrices where the experts (e.g. designer, controller, department heads) estimate influences from cost drivers on activities, or cost drivers on roles. By estimating the strength of influences in numbers (0=no,1=little, 2=medium and 3=high) influence a distribution of influences can be generated. Instead of the more easy way with numbers it also can be directly or sequentially be estimated how much effort in hours will be caused by expressions of cost driver states. Hence the cost driver states can be of linear, exponential or also discrete values (not shown in example). The model can be implemented in spreadsheets.

5.2 Procedure: company-specific build-up of change process model

As dependencies between elements vary across companies, they must be raised individually for each company.

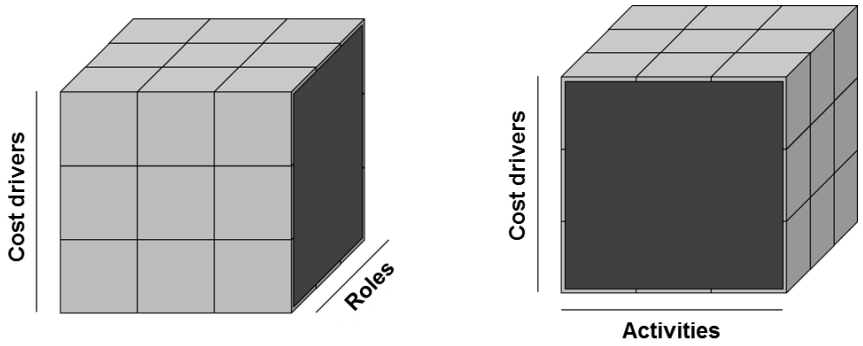

Figure 2. Deriving the basic parts of the change process model

Performing the following steps for company-specific build-up of the change process model:

- Step 1 - Inquiry of domain/element parts (no./type of cost drivers, roles, activities).
- Step 2 - Inquiry of Influence matrix cost driver / roles.
- Step 3 - Inquiry of Influence matrix cost driver / activities.

5.2.1 Step 1 - Inquiry of domain/element parts

In the first step, the model components (cost drivers, activities and roles) need to be determined in company-specific way. Supported by generic templates (Gebhardt et al., 2015) for the elements of cost drivers (e.g. complexity, newness, time, urgency, interdependence, dynamic,...), activities (e.g. development of solution alternatives, assess the change request, create change request, technical analysis of the change,...) (VDA, 2010) and roles (e.g. design, development, purchase,...) these which appear in the company must be taken and complemented by additional company-specific elements of cost drivers, activities and roles. The actual occurring in the companies of the change process model in maximal value are the result of this step. All important cost driver acting in the company, all running process steps and all roles involved in the change process must be captured here. The further analysis in the context of the process model is comprised to them.

5.2.2 Step 2 - Inquiry of Influence matrix cost driver / roles

In the second step, the influences of the identified costs drivers on the roles involved in the change process in the company is collected (left in Figure 2). Thus line by line need to be assessed whether and in what form (low/medium/strong) each of the roles will be affected by the relevant cost drivers. The survey is at best experts of the respective departments/roles to carry out, alternative by experts with overview (e.g. head of development, controlling). Strongly situation-specific interactions are identified in the survey, it should be noted this separately by comments/description in the model. The result of this step is a weighted influence matrix that represents the system behaviour of the interactions of cost drivers and roles within the company.

5.2.3 Step 3 - Inquiry of Influence matrix cost driver / activities

In the third step, bringing the influences of cost drivers to the change activities within the company is made analogue. The result is the weighted influence matrix of cost drivers and activities, that represents the system behaviour of the interactions of cost drivers and activities within the company.

5.3 Specification of systems behaviour

The system behaviour can be specified for all involved domains (E.g., roles, activities, etc.) each in comparison of main influencing factors (E.g. cost drivers). The cost drivers can express yes/no or have one or more discrete or continuous state values, which are applied to the influences (values from the impact matrices). To derive "situational relations" from the overall behaviour of the system the respective "element behaviour" can be combined. Hence general trade-off considerations at the level of individual cost drivers and individual disciplines (see Figure 3) can be made.

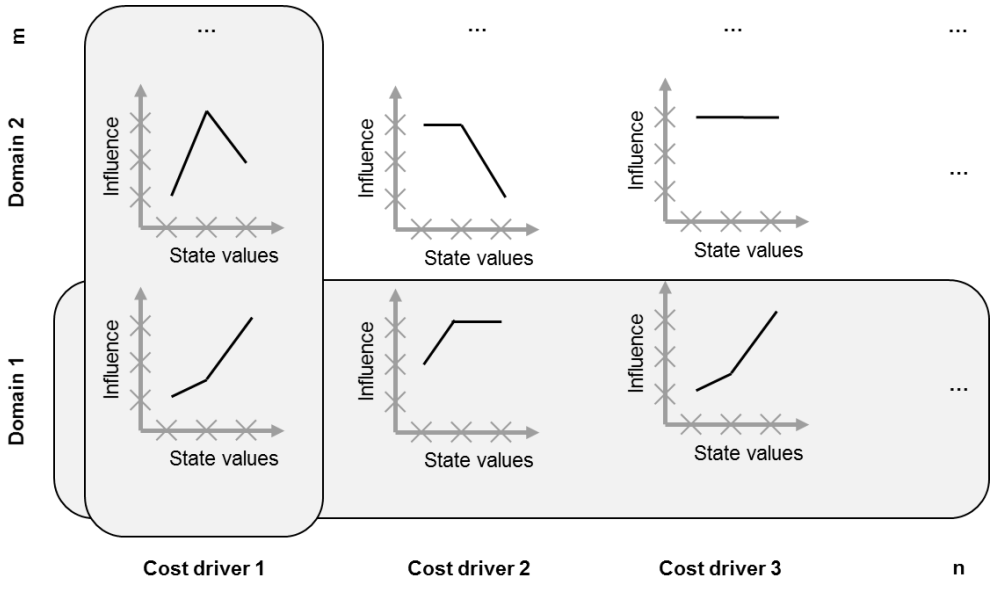

Figure 3. System behaviour diagram as m x n matrix of single state fields

5.4 Implementation

Based on the derived impact matrices, the model can be implemented (Figure 4). The case is about individual cost drivers and, in the simplest case, the case-specific states (weighted cost drivers) classified, e.g. complexity degree of change in expression "low = 1", "2 = medium" or "high = 3". The impact of cost drivers on the activities and roles are represented through impact matrices (cost drivers /roles, cost drivers/activities), can be raised by companies in workshops with minimal time in the order of hours. A simple column/row sum of the multiplication expression values of cost drivers with the cells of the impact matrices results in impact profiles of the change effort/cost, which can guide the change manager. On this basis can be decided as, where and when it pays to employ measures to reduce costs.

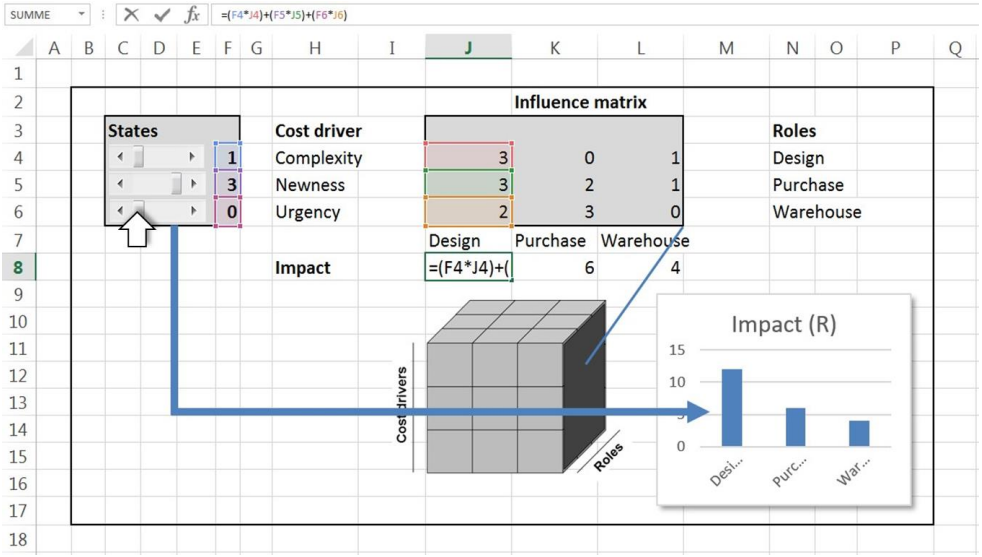

Figure 4. Simplified implementation

6 INFLUENCING INDIRECT CHANGE COST

Based on the change process model, systematic and case-specific cost reduction measures can be applied, guided by impact profiles of the domains cost drivers, activities and roles (Figure 5).

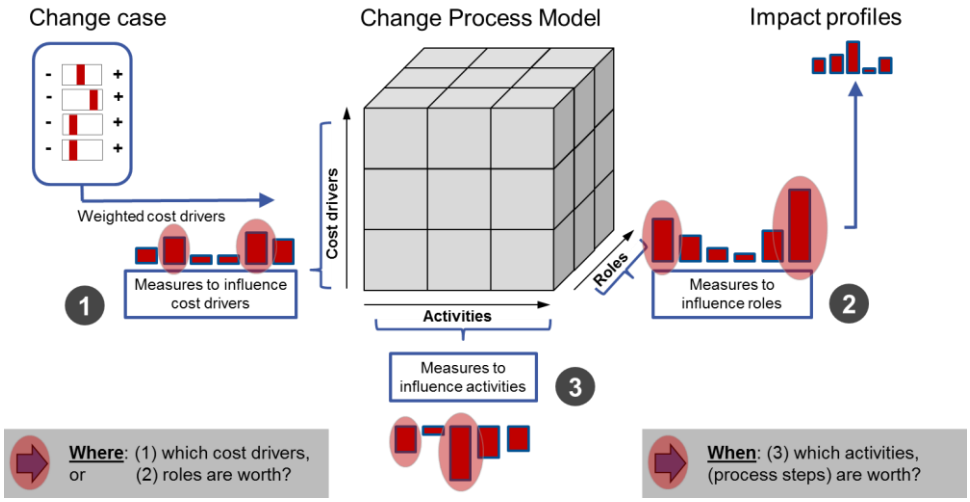

Figure 5. Fields of action for measures with the change process model

Examples of measures can be: in the area of cost drivers of the targeted elimination or reduction of influences (as constructive or organizational complexity reduction, reduce parts, common parts use, develop alternative solutions), in the area of activities an efficiency of process steps, process chain

optimization, customer involvement and in the area of the roles improved interface management, integration of better and earlier, as well as personnel optimizations. Measures must be company-specific matched to effectively intervene on a given system behavior.

6.1 Measures to reduce indirect cost

To specifically influence indirect change costs, measures must be identified on the one hand, that are practically applicable in the company. On the other hand, the effects of these measures need to be quantified company-specific. This company-specific catalogues of measures can developed, and be used for future change cases. To reach tangible individual steps, a list of general measures to influence the indirect cost of change was developed starting from a thematic literature review. To do this, thematically appropriate literature has been researched, which deals with aspects of the indirect cost of change. Identified in the literature are fields of overhead cost management (Gleich and Marfleet, 2012; Kaplan and Anderson, 2007; Brimson, 1991; Müller, 1992), lean development (Mascitelli, 2007), process optimization (Seidenschwarz, 2008; Fischermanns, 2013), cost effective design (Ehrlenspiel and Meerkamm, 2013; Schmidt, 1996; Mörtl 2002; Mörtl, 2012), and change management (Fricke, 2006; Lindemann and Reichwald 1998; Conrat Niemerg, 1997). From these sources, over 200 individual measures were identified, which were merged after consolidation and generalization to general measures approximately 70 strong in a list with descriptions.

Effect	C1	C2	...	Cn		A1	A2	...	An		R1	R2	...	Rn
M1	x													
M2	3	2	1	3		2	3	1	0		3	1	2	1
...						x						x	x	
Mn		x				x	x							x

1

2

Figure 6. Inquiry of measures and their effects on cost drivers, activities and roles

To make concrete measures for a company available, they must be raised (1), see left column in Figure 6, and (2) assessed how they impact cost driver (C), activities (A) and roles (R), see horizontal cells in Figure 6. To do this is to ask for each measure: whether and how much the individual cost drivers, activities and roles impact (effect) efforts/costs. This can be done via (weighted) impact matrices, by for each cell the presence of effect with "x" (e.g. M1 and Mn in Figure 6) - or more detail still, the strength of the effect (0 = none, 1 = little, 2 = medium and 3 = strong effect, e.g. M2 in Figure 6) expert assessed.

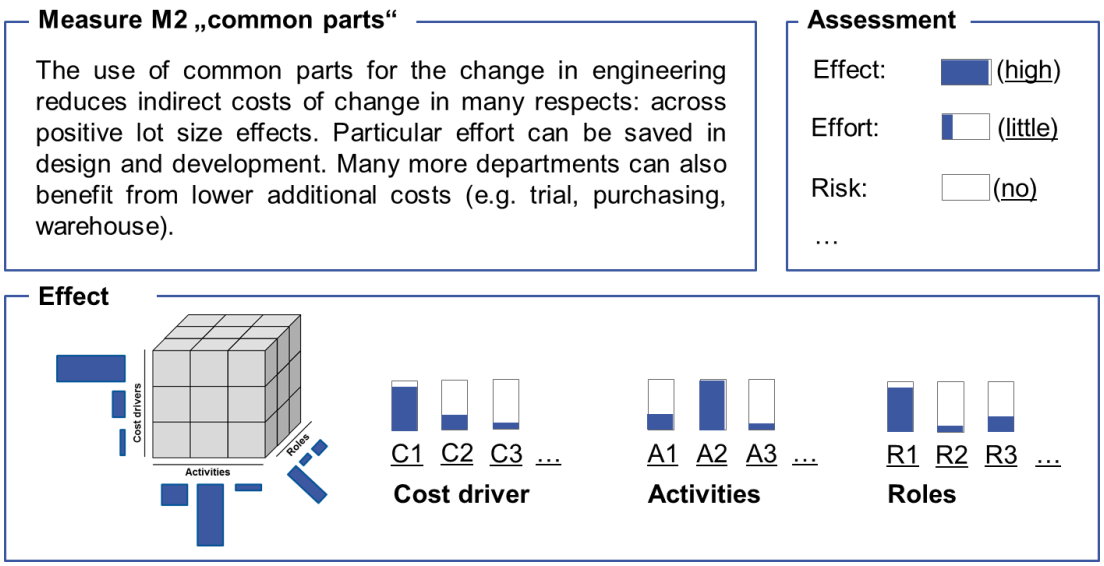

Figure 7. Example item of catalogues of measures

On this basis, it is possible to create company-specific catalogues of measures (example item shown in Figure 7), which clearly permit the use in specific cases of change the designer, change managers or stakeholders in the change process.

6.1.1 Classification of measures

Measures can be classified by the domains of the change process model. Measures that influence cost on highest change case level will be applied by alternative change solutions. Next level is "cause measures" that work on reducing cost drivers (e.g. design parameters). Last step is "impact measures" that effect the outcomes of cost drivers and influence activities and roles.

6.2 Procedure to reduce indirect cost

Figure 8 shows overview of the essential steps that must be performed to reduce the indirect cost of implementing a change.

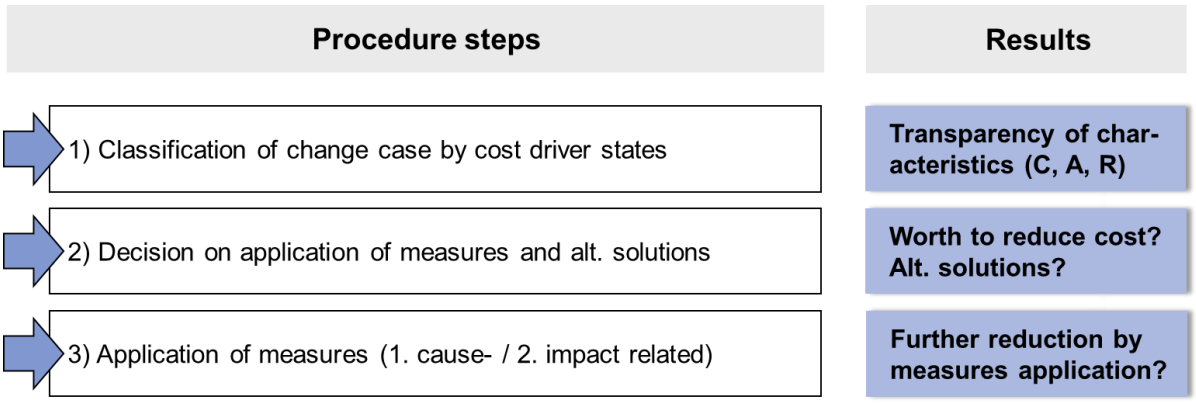

Figure 8. Basic steps to reduce indirect change cost

6.2.1 Classification of change case by cost driver states

First, the case on the basis of the characteristics of its cost drivers must be classified. This provides transparency about costs to be expected in the individual process steps and areas of the company in the change process model. The values of cost drivers, the activities and involved roles are the result of the first step. The expected overall effort that evokes the change is first decision criterion for the next step.

6.2.2 Decision on application of measures and alternative solutions

Based on the total effort, in the second step, it must be decided, if it is worth of using cost reduction measures. The expected costs/effort of the change is so small that the overhead for cost reduction measures is not justified, the process here is canceled. The expenses for cost reduction measures is, however, justified, must decide further whether it is worth the development of alternative solutions for the change. This is the case, the best, based on the classification of the relevant cost drivers must be identified from the developed alternatives. Unless a cheaper alternative exists, the process can also be cancelled if the cost reduction goal is reached. Otherwise, the modification or the cheapest alternative is taken to a more detailed measure usage.

6.2.3 Application of measures (1. Cause- / 2. Impact related)

Individual measures must be used in the most detailed case to implement further cost cuts. This should be done at first, cause-related and subsequent impact-related if necessary. Cause-related attack directly on the cost drivers of the respective change/alternative and reduce their value. This is effective enough, the process can be canceled. Reducing the cost driver is already maxed out, measures that impact roles or individual process steps can be used to further improvements.

6.2.4 Visualization of procedure

The procedure is visualized in Figure 9. Here the values "A", "B", "C" must be company-specific derived and cannot be generalized.

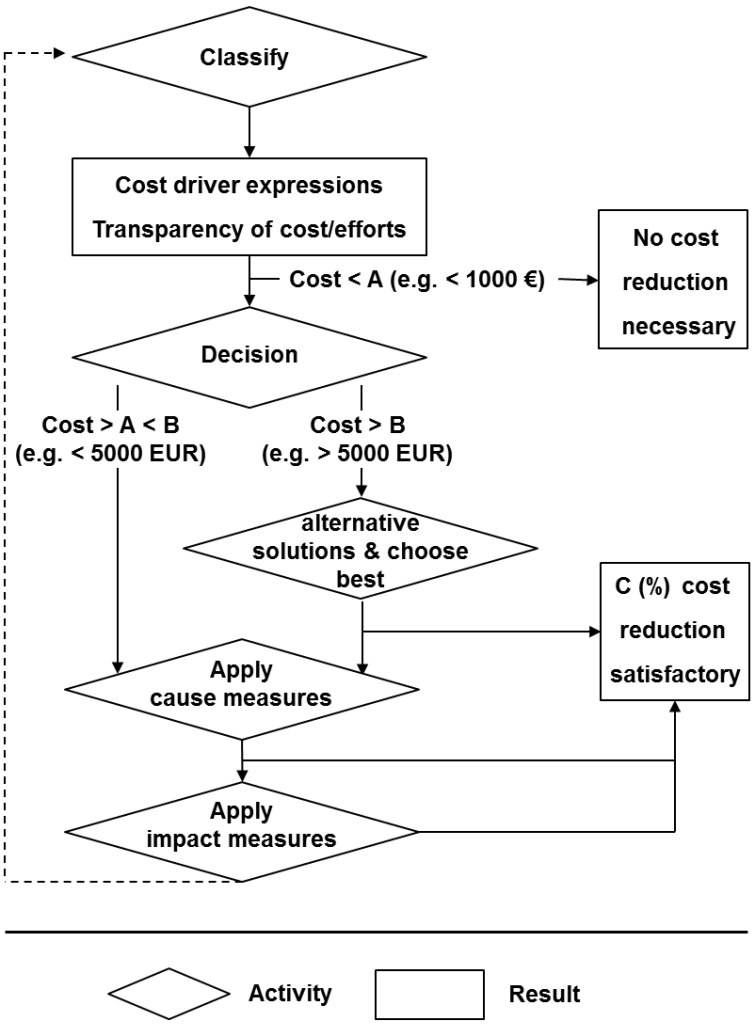

Figure 9. Flow chart of indirect cost reduction procedure

7 CONCLUSION AND OUTLOOK

The presented approach represent a fast and easy possibility to model the system behaviour of indirect cost of engineering changes in a company-specific and change case specific level of detail. The accuracy is limited to the quality of expert assessment. The applicability of the method can be stated for cases (products or companies) where indirect cost of engineering changes describe themselves by main influence factors and their system behaviour to the participating disciplines/elements generally impact matrices is good or is not predominantly situation-specific variable.

Our findings in practice were e.g. in two cases one cell of impact matrices were too situation-specific to be assessed in a general way. This observation occurred in one company with a 12x8 matrix and one with a 6x7 matrix. Therefore the percentage with respect to the number of cells was in the order of 1-2%. If situation-specific cells represent higher values or cells with high importance (e.g. main cost drivers for a company), the applicability must be questioned. On this basis the presented analysis methodology can be transferred to other concerns beyond engineering change management.

For previous work on the method refer to (Schmied et al., 2016). For a method to obtain higher estimation accuracy for indirect change cost with more detailed data collection refer to (Gebhardt et al., 2016). Future work will concentrate on theoretical aspects of the matrix methodology and evaluation.

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ACKNOWLEDGMENTS

Das IGF-Vorhaben 18492 N der Forschungsvereinigung Forschungskuratorium Maschinenbau e.V. - FKM, Lyoner Straße 18, 60528 Frankfurt am Main wurde über die AiF im Rahmen des Programms zur Förderung der industriellen Gemeinschaftsforschung (IGF) vom Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages gefördert.