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CHOOSING THE RIGHT MEASURES TO IMPROVE COLLABORATION BETWEEN DESIGN AND SIMULATION DEPARTMENTS

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Abstract

Increasing complexity of products and design processes leads to intensive collaboration of different stakeholders in technical product development. This causes a demand for suitable methods of collaboration across department interfaces, as between design and simulation. The paper investigates typical barriers of collaboration at this interface and measures to overcome them. Methods of complexity management form links based on literature and empirical data from online surveys and interview studies. The framework uses a set of structural metrics to analyse collaboration networks systematically.

Keywords: *structural complexity, communication, process improvement, collaboration, design management*

1. Introduction

With the diversification into different sub-disciplines like electronics, industrial design, informatics, as well as design and simulation, engineering design processes are complex systems (Kreimeyer, 2009), where communication plays an important role (Maier, 2007; Sosa et al., 2007), especially in inter-disciplinary design. Within this complex system, the focus of this paper is on the collaboration between design and simulation departments. This is and will be a major topic in design management as the number of simulations as well as their complexity and the generated data has increased dramatically within the last years and is about to continue that way (Reicheneder, 2015; Norris, 2017).

This paper combines empirical data on barriers between design and simulation departments with insights from communication science and structural metrics for network analysis. The presented approach is tailored to large organizations where design and simulation exist as two separate departments. However, many of the findings can be transferred to the collaboration of people from these two disciplines even if they are organised in a different way, e.g. when simulation is regarded as integrative part of design.

The overall goal is to provide recommendations for suitable improvement measures that take the specific situation of companies and their collaboration structure into account. This is important, as preliminary work has shown that standard measures like process standardization are the key to success for some companies while others regard it as not possible or necessary (Schweigert-Recksiek et al., 2019).

2. State of the art

2.1. Inter-departmental collaboration in engineering design

This work is grounded on the Conceptual Framework of Communication in Engineering Design by Maier (2007), in which she defines factors influencing communication in engineering design. A set of 120 recommendations for communication in engineering design are listed in Maier et al. (2011). They are the result of a systematic literature review and are finally grouped in the four categories 'information', 'individual', 'team', and 'organization'. They are applicable for any sort of communication in engineering design and are not limited to the focus of this paper - the collaboration between design and simulation departments. However, due to their generic nature, all of them are applicable for this specific area.

The understanding for the barriers this paper tries to overcome originates a combination of research from communication science by Eppler (2007) and insights from the field of human behaviour in design.

As in Maier (2007), communication in this research refers to the interaction between people and the transmission of information in a social and organizational context. It is part of collaboration, defined as the act of working together in a project or any other sort of goal-oriented activity. This is based on the "3C Collaboration Model" by Fuks et al. (2007), in which collaboration includes communication, coordination, and cooperation.

2.2. Collaboration of design and simulation departments

Previous work on the collaboration of these two departments has been conducted by Herfeld et al. (2006) and Deubzer et al. (2005), who analysed communication between design and simulation departments. Their results show that one of the main issues in CAD-CAE-integration is the unification of goals. As Herfeld puts it, now in the position as head of vehicle test department of an automotive OEM "A conflict of objectives is the central problem for efficient collaboration of design and simulation departments. While simulation experts try to design a product that meets all functions and requirements, design engineers are responsible for meeting time and cost targets." Beside this issue of goal setting, many tools help to simplify the collaboration. Schönwald et al. (2019), for example, showed in an empirical study that simulation data management tools are very beneficial and more widely used than for example test data management. Eriksson et al. (2014) as well as Petersson et al. (2013) emphasise, also based on an interview study, that CAD-integrated FEM systems are used systematically in design departments of many companies and that these simulations are performed efficiently.

2.3. Structural analysis of collaboration networks

As further described in the following sections, this research uses structural network analysis firstly to identify barriers in the collaboration of design and simulation departments and then to come up with suitable recommendations for improvement. Concerning structural analysis of engineering design collaboration networks and metrics for engineering design process, this research builds on the work of Kreimeyer and Lindemann (2011). Using the Goal-Question-Metric approach as described by Basili and Weiss (1984), Kreimeyer defines a set of metrics for engineering design processes. The resulting measurement system is used in this framework. A similar approach is described in Mathieson and Summers (2017). They describe a protocol that uses e-mail exchange and other data to build networks that can be analysed via network metrics. This can help to identify member roles and work schedules. Songhori and Nasiry (2019) built on the misalignment theory that compares organizational structures and product structures. This also includes analyses of the decision making structure that can be applied to the collaboration of design and simulation departments as well.

3. Methodology

3.1. Research gap and research questions

As previous research on the integration of simulations like FEM and CFD in the product development process has focused mainly on technical aspects such as tools and data, there is a need to further

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investigate the dimensions of people and process (Motte et al., 2014). Especially, a systematic way to identify suitable improvement measures building on an empirical foundation is missing.
Therefore, the following research questions have to be asked:

- RQ1: What are typical barriers in the collaboration of design and simulation departments?
- RQ2: What are appropriate measures to enhance communication and collaboration between design and simulation departments?
- RQ3: How can barriers of collaboration and improvement measures to overcome these barriers be matched taking into account the specific boundary conditions and collaboration structure of different companies?

3.2. Research design

This framework was built using the design research methodology by Blessing and Chakrabarti (2009). As they propose for the visualisation and structuring of research projects, the following reference model was built (Figure 1).

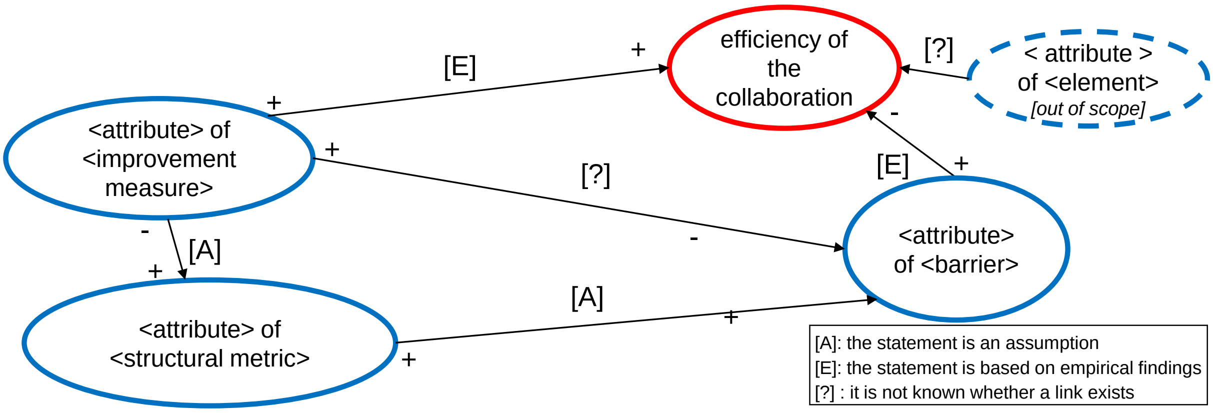

Figure 1. Reference model according to Blessing and Chakrabarti (2009)

It shows how empirical data is used to investigate which barriers hinder efficient collaboration and which improvement measures support it. Structural metrics are used to connect barriers and recommendations for improvement measures or to identify barriers in collaboration networks. The findings are generic and can be applied to any company with design and simulation departments.

3.3. Preliminary work

Some preliminary work has been published on parts of the approach this paper presents as a whole. Schweigert et al. (2017a) initially showed an earlier version of the framework. Knippenberg et al. (2018) presents the structural metrics and their implementation in a graph analysis tool in detail. Schweigert-Recksiek and Lindemann (2018) elaborates on the barriers between design and simulation departments while Schweigert-Recksiek et al. (2019) builds the connection between barriers and recommendations based on a multivariate analysis of survey data coming from Schweigert et al. (2017b). All these parts are integrated in the framework of this paper, supplemented by the description of the research methodology and questions, the table of recommendations as well as an industrial case study.

4. Results

4.1. The framework

Figure 2 shows the overall approach of this paper (extended from Schweigert et al., 2017a). It consists of four generic phases: situation description, characterization, measure selection, and implementation. The upper row shows the inputs for each phase, while the outputs are depicted below the phases.

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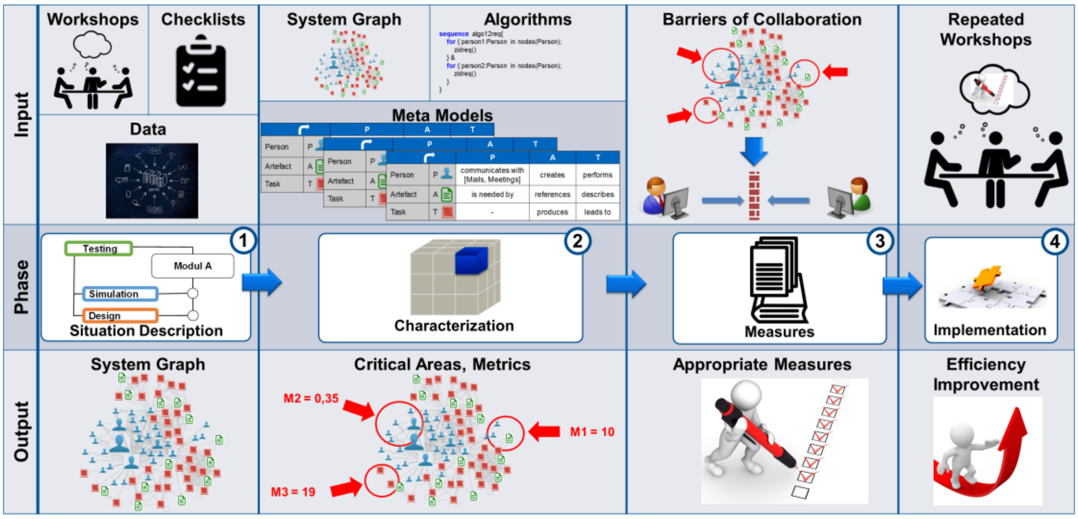

Figure 2. Approach for the improvement of collaboration between design and simulation departments (extended form Schweigert et al., 2017a)

Workshops, checklists, and data analysis (e.g. email correspondence, meeting calendars) are used to form system graphs of collaboration in **phase 1**. These graphs are analysed in **phase 2** based on the metamodel in Figure 3 to come up with structural metrics that can identify possible barriers on the one hand and help implement improvement measures downstream in the process. By a comparison with typical barriers of design and simulation departments in **phase 3**, the specific barriers of a given company are identified before they are mapped to fitting measures to overcome them. This forms the input of repeated workshops in **phase 4**, where the final measures for implementation are selected in order to improve the overall efficiency of the collaboration between design and simulation departments.

		P	A	T
Person	P	communicates with [Mails, Meetings]	creates	performs
Artefact	A	is needed by	references	describes
Task	T	-	produces	leads to

Figure 3. Metamodel for the collaboration of design and simulation departments

For the approach shown in Figure 2, three scenarios were elaborated (cf. Table 1):

1. A given company wants to improve collaboration without specific preparation.
2. A given company knows, where their specific barriers are and wants to overcome them.
3. A given company has already decided, which measures to implement, but does not know how and where exactly.

Table 1. Scenarios how to use the approach

Preparation of the company	***Scope***	
	a: Data-Driven	**b: Workshop-Based**
No preparation	Whole Process: Phases 1-4 Metric-based identification of barriers and recommendations	Short Process: Phases 1,3,4 Checklist-based identification of barriers Matrix-based selection of measures
Identified Barriers	Metric-based identification of recommendations	Matrix-based selection of measures
Selected Measures	Metric-based implementation	Workshop-based implementation support

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For **Scenario 1**, the whole approach (phases 1 to 4) is gone through. After gathering data (phase 1) and characterizing the situation (phase 2) via system graphs (a) or only based on workshops (b), recommendations for improvement are made (phase 3). These recommendations lead to measures that are implemented (phase 4) based on metrics (a) or only based on additional workshops (b).
For **Scenario 2**, where barriers have already been identified, either additional data is acquired and analysed (phases 1 and 2; a) or recommendations for improvement are derived directly in workshops (b; phase 3). These measures are either implemented based on metrics (step 4; a) or only based on workshops (b).
For **Scenario 3**, where measures have already been chosen, either additional data is acquired and analysed (back to phases 1 and 2; a) to support the implementation (phase 4; a) or merely the implementation of measures is supported by workshops and tools (phase 4; b).

4.2. The ingredients

4.2.1. Barriers of interdepartmental collaboration

The barriers in the collaboration between design and simulation departments that are used in this paper are grounded on the findings of an online survey described in Schweigert et al. (2017b) and a following interview study (Schweigert-Recksiek and Lindemann, 2018). The list of 20 barriers is based on 31 communication barriers as described in Eppler (2007), who reviewed findings from social and engineering sciences, and classified knowledge communication barriers into three groups: barriers that affect mainly managers, those relevant for experts, and those important for both roles. These 31 barriers were used in the composure of the interview guide for the study described in Schweigert-Recksiek and Lindemann (2018). Figure 4 lists the resulting typical barriers between design and simulation departments.

People	B06	Generation gap
People	B07	Handling different human characters
People	B09	Interdepartmental communication and feedback culture
People	B10	Lacking acceptance and inadequate understanding of the capabilities of simulation experts
People	B12	Mistrust in simulation results
People	B13	No close coupling between departments (e.g. global distribution and central simulation department)
People	B15	Physical distance that prevents face-to-face communication
Data	B05	Conflict between explanation of complex issues vs. high documentation effort
Data	B08	Lacking information sharing towards the simulation department
Data	B19	Unstructured information sharing
Tools	B20	Inefficient usage of CAD-integrated FEM systems
Process	B01	Difficulties in Concurrent Engineering
Process	B03	Challenging coordination of design and simulation processes
Process	B04	Inefficient frontloading and dependency of simulation on design and test departments
Process	B11	Missing structures of collaboration (e.g. trigger points)
Process	B14	No customer focus
Process	B16	Lack of transparency in the prioritization of simulation orders
Process	B17	Redundant time-consuming iterations (e.g. due to outdated geometries)
Process	B18	Standardization in the presence of diverse projects
Product	B02	Conflict of objectives between design, simulation, and test

Figure 4. Set of barriers between design and simulation departments (adapted from Schweigert-Recksiek and Lindemann, 2018)

4.2.2. Recommendations for improvement measures

The basis of the results in this paper is an understanding of communication in engineering teams and especially between design and simulation departments. Table 2 lists the recommendations that are a result of a systematic literature review. Hundreds of papers mainly from engineering design journals were analysed and a final set of 131 sources was used to formulate the recommendations under the influence of Maier et al. (2011). Table 2 also shows the transfer of these generic recommendations in column one to the topic of collaboration between design and simulation departments in column two based on examples from the expert interviews. The term "expert" is used according to the defintion of Liebold and Trinczek (2009), as a person with detailed and specialized knowledge in a certain, clearly defined domain - in this case the collaboration of design and simulation departments. Concrete methods and tools, on which more material is available for the implementation workshops of phase four, are marked in **bold**.

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Table 2. Recommendations and transfer to collaboration between design and simulation departments (concrete methods and tools in bold; part 1)

#	Generic recommendation	Transfer to design and simulation
1	Effort and good information transmission in the initial phases	Use **hand-drawn sketches** in kick-off meetings that include members of both design and simulation department
2	Scheduling and identification of priorities and needs	Introduce trigger points for communication in the overall design process (e.g. via decision meetings using the **RACI Method**)
3	Appropriate information sharing among departments during product development	Preparation and pre-configuration of the **CAD-integrated FEM systems**
4	Information sharing tools and networks	Use shared **PDM and SDM systems**
5	Understanding of the entire project at all levels and common terminology	Encourage communication between departments via **simulation templates** and **simulation reports**
6	Interaction and sharing questions, ideas, and values	**Shared offices** between design and simulation department heads
7	Approach of conflicts pro-actively and close communication to resolve them	Push for regular personal meetings (cf. **Scrums**)
8	Feedback, reviews, and evaluations at all levels	Implement a change process with automatic **trigger points** for reviews
9	Team motivation and rewards	Conduct **teambuilding measures**, especially for internationally distributed design and simulation teams
10	Examination and evaluation of the factors involved in each decision	Employ decision makers that respect simulation results
11	Empowerment of the skills of employees through education and training	Training and mentoring of design engineers by simulation experts when using CAD-integrated FEM-systems
12	Experienced designers and experience of previous successful projects	Use **lessons learned meetings** after projects as well as best practice databases
13	Definition of clear and specific objectives	Combine the functional goals of the simulation department and the cost-driven and size-driven goals of the design departments in **kick-off workshops**
14	Choice of right people for each job and trust in their responsibilities	Provide simulation experts in central simulation departments with responsibilities instead of merely using them as service providers for the design departments
15	Clear definition of jobs and expectations	Define clear division of tasks between design and simulation departments in initial phases of the project (e.g. via **process standardization/tailoring)**
16	Reinforcement of organizational values and appropriate management style	Actively advertise the capabilities of simulation departments

4.3. The connection between barriers and recommendations

The connections between barriers and recommendations were drawn mainly from the interview study described in Schweigert-Recksiek and Lindemann (2018) as well as the survey data analysed in Schweigert-Recksiek et al. (2019). Also, all of the interviewed experts not only mentioned barriers in the collaboration of the departments, but also named improvement measures that are either already implemented in their companies or are suitable to overcome the barriers in their opinion. Furthermore, every barrier from Figure 1 is connected to an underlying reason for communication barriers from Eppler (2007). Using this foundation and understanding built up by the literature review and the empirical studies, connections were drawn between the recommendations in Tables 2 and 3 and the barriers in Figure 1. The resulting connections were double-checked by the factors of communication from Maier et al., 2011. The result is a connection matrix that links the identified 20 barriers with the 16 recommendations (Figure 5). As the barriers

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6, 7 and 14 are rather generic, no specific connection could be derived from the survey data so that they are only linked to recommendations based on the expert interviews. For barriers 16, 18, and 19, no matching link was found in both the expert interviews as well as the survey data. Therefore, only survey data was used to link them to appropriate recommendations.

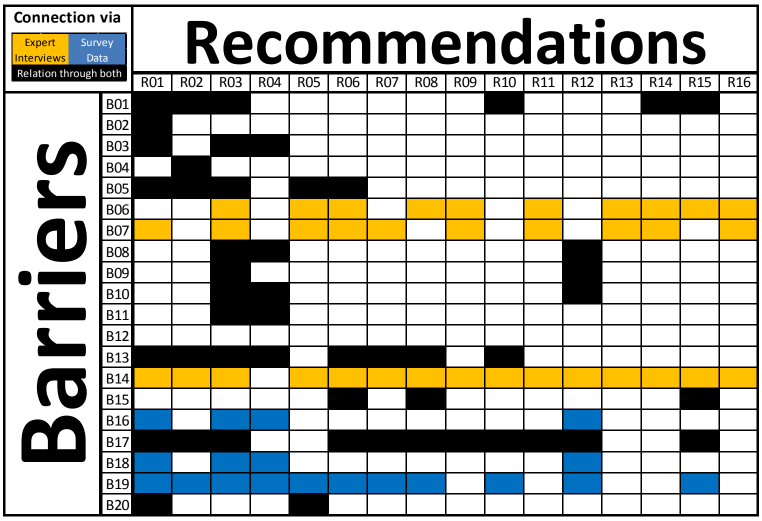
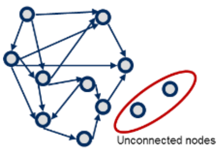


Figure 5. Connection matrix linking barriers and recommendations

Table 3. Adapted set of metrics for design and simulation departments (part 1)

#	Metrics of Kreimeyer (2009)	Adapted Metrics	Barriers
8	Number of unconnected nodes 	M 7.1 Number of unconnected people (especially if they are indirectly connected via tasks or artefacts)	B 8, 10, 17
		M 7.2 Number of unconnected nodes across departments (simulation engineers who do not participate in design tasks/meetings)	B 9, 12
		M 7.3 Number of designers who do not use CAD-integrated systems	B 20
		M 7.4 Number of unconnected people to tasks	B 8, 10, 17
		M 7.5 Number of unconnected Artefacts to people (Person does not have access to task-relevant artefact/information)	B 4, 8, 17, 19
15	Number of feedbacks	M 15.1 Number of feedbacks between design and simulation engineers	B 8, 16

4.4. Systematic network analysis with structural metrics

Based on the work on structural metric for engineering design processes by Kreimeyer (2009), a set of 16 metrics for the collaboration of design and simulation departments was defined (all of them listed in Knippenberg et al. (2018)). Its purpose is to identify possible barriers of collaboration or support the implementation of a certain improvement measure. Using the Goal-Question-Metric approach by Basili et al. (1994), it was ensured that there is at least one metric each that indicates the existence of the 20 barriers or the effect of the 16 recommendations as stated in the reference model in Figure 1.

Figure 6 shows an example of the connection of barriers, recommendations and metrics.

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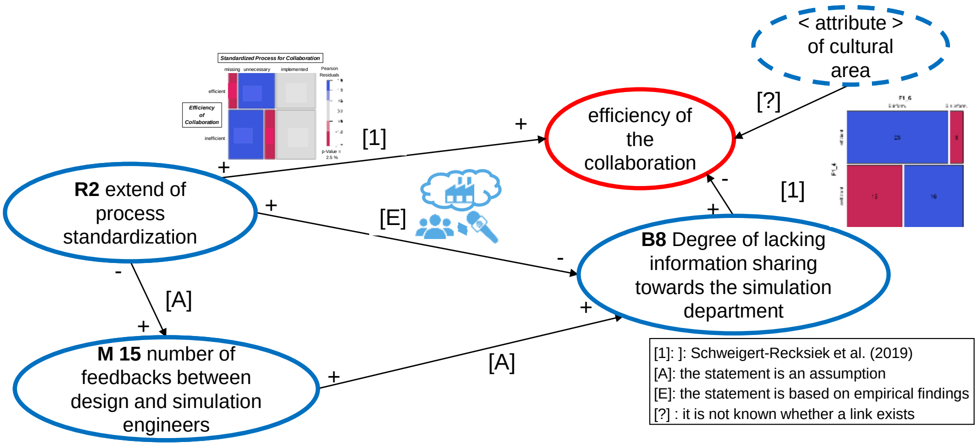

Figure 6. Reference model using the connection between process standardization and lacking information sharing towards the simulation department

As shown in the interview study ([E] in Figure 6) described in Schweigert-Recksiek and Lindemann (2018), there is connection between recommendation R2 (*Introduce trigger points for communication in the overall design process (e.g. via decision meetings using the **RACI Method***)) and barrier B8 (*Lacking information sharing towards the simulation department*). Both of them can be directly linked to the efficiency of collaboration with the survey data analysed in Schweigert-Recksiek et al. (2019). Metric 15.1 (*Number of feedbacks between design and simulation engineers*) is assumed to be a good indicator for the extend of barrier B8 as well as a measure on how successful recommendation R2 was implemented. Table 4 shows two examples of the metrics listed in Knippenberg et al. (2018) and how they are used in this framework. Metrics of Kreimeyer (2009) are first adapted to the context of the collaboration of design and simulation departments, before the last column links them to one or several of the barriers. Due to the page limit, not all 16 metrics are presented here, but the explanatory example of M8 (*Number of unconnected nodes*) and M15 (*Number of feedbacks*).

Table 4. Participants of the case study workshops

#	Position
1	Head of Processes, Methods, and Tools
2	Function Development Engineer
3	Diagnosis Analyst
4	Series Production Engineer
5	Design Engineer
6	Head of Function Development

The metrics stated above can be calculated semi-automatically from system graphs. This gives the opportunity of identifying barriers in a given network, systematically or support the implementation of improvement measures based on the current collaboration structure.

5. Application in a case study

As shown in Table 1, the framework can be used in different scenarios. For a first case study with an industry partner from a heating systems company, a workshop-based approach without specific data preparation was used. Current development processes were analysed and target processes were formulated as part of a case study to implement a digital twin (cf. Schweigert-Recksiek et al., 2020). In order to better integrate the simulation department in the product development process, six workshops with participants from different departments were conducted (cf. Table 4).
19 out of the 20 barriers (cf. Figure 1) were confirmed by at least one expert, most of them by more (average confirmation of 3.6 out of 6). There was no confirmation for barrier B14 (*No customer focus*). Three of the barriers were confirmed by all experts, one of them being B4 *(Inefficient frontloading and*

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dependency of simulation on design and test departments). As this barrier was rated as the most hindering one in the current collaboration by the participants, an improvement measure was search for that can overcome it. According to the connection matrix in Figure 5 R02 *(Scheduling and identification of priorities and needs - decision meetings using the.* ***RACI Method)*** is suitable here. RACI refers to Responsible, Accountable, Consulted, Informed. Figure 7 shows a part of the new target process for a tolerance analysis. After the simulation department analyses the tolerances with FEM simulations and created an analysis report (red boxes), a simulation engineer is integrated in a consulting role in the decision meeting about the correctness of the draft, the design department is accountable for.

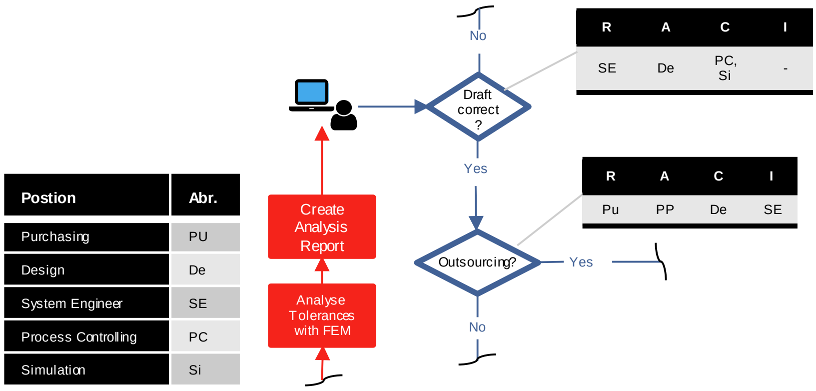

Figure 7. Part of the target process for a tolerance analysis

This approach was applied on a total of six new target processes with the result of a far more intensive integration of simulation engineers in the decision process. As from now on simulation experts will be part of the decision meetings instead of just providing analysis reports for them, their integration into the overall information flow is enhanced, which helps to make frontloading of simulations more efficient in following projects, as they already know which information is important for the decision meetings and how it has to be presented.

6. Discussion and outlook

The results of this paper enable the analysis of complex networks of the collaboration between design and simulation departments. Despite the effort spent on building a reliable foundation, limitations remain. Built on the results of both an empirical as well as a literature-based study, the connections between barriers and recommendation seem reliable. However, it is thus far only partly grounded on extensive and statistically relevant data that would include representative data from multiple companies in various regions and industries. Still it was possible to answer all research questions: A set of typical barriers in (RQ1) as well as improvement measures (RQ2) for the collaboration of design and simulation departments are presented. They are matched, taking into account the boundary conditions and collaboration structure of a given company (RQ3). First evaluations with companies not part of the initial interview study have affirmative results. Future research will focus on the implementation of the presented concepts, mostly in graph-based complexity management tools. The authors have started a research project with a Swiss automotive supplier to prove the applicability in a large and complex organisation. The validity of both, the connections between barriers and recommendations as well as the applicability of the recommendations to enhance collaboration will be tested here. Therefore, a tool for the semi-automatic analysis of networks will be provided and applied in the industry case studies.

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