DOI NUMBER: 10.19255/JMPM01207

KEYWORDS ◘ CAD-CAE ◘ Structural complexity management ◘ DSM ◘ DMM ◘ MDM ◘ System graph ◘ Collaboration and collaboration ◘ Human behaviour in design

ENHANCING COLLABORATION between Design and Simulation Departments by METHODS OF COMPLEXITY MANAGEMENT

Sebastian Schweigert
Technical University of Munich, Chair of Product Development
schweigert@pe.mw.tum.de

Mesut Çavuşoğlu
Technical University of Munich, Chair of Product Development
mesut.chavushoglu@tum.de

Udo Lindemann
Technical University of Munich, Chair of Product Development
lindemann@pe.mw.tum.dee

ABSTRACT

The significance of CAD-CAE coupling has grown with the increasing use of simulations in development processes. With the focus on technical aspects like simulation data management in literature, however, there is a lack of research on the implications on collaboration. This paper uses methods of structural complexity management to improve communication and collaboration between simulation and design departments. Design structure matrices and multiple domain matrices are derived from system graphs that come from interviews. A case study uses these methods to handle data to enhance collaboration between departments. The results are techniques to deal with lacking information and low degrees of connectivity in the matrices. After an overlay of different matrices, standard procedures like triangulation and clustering can be applied that would otherwise not have been sensible. This leads to knowledge clusters and sequences of documents and task that help to integrate simulations more smoothly into the product development process.

Introduction

Compared to the past, simulation is taking an increasing role in product development today (Maier et al., 2009). The iterative procedures in product development create a huge demand for the integration of simulation in the product development process as simulation and design departments collaborate with each other frequently. Deubzer et al. (2005) considered a holistic approach for the problem by defining the four dimensions of the integration problem in terms of product, people, data, and tool. Kreimeyer et al. (2005) added the process dimension and completed the five dimensions of the integration problem. Thus far, despite the increasing role of simulation in product development that demands for a holistic approach (Maier et al., 2009), the tool, data, and process dimensions have been the focus of researchers (Kreimeyer et al., 2005). Kreimeyer et al. (2006) were then the first to apply methods of complexity management in research on CAD-CAE integration. This is also the topic of this paper, which presents a methodology to deal with very low degrees of connectivity, unreliable data, and unnecessary input.

2 State of the Art

Since the beginning of the application of simulation tools in product development, numerous attempts have been made to integrate simulation in the product development process. However, these attempts always focus on specific, often technical aspects. For example, direct CAD-CAE data exchange first started in the 1990s and was followed later by parametric modeling (Hirz et al., 2013, p. 31).

For publications on further technical aspects of CAD-CAE integration like data interoperability see for instance Forsen & Hoffmann (2002), Schumacher et al. (2002), Assouroko et al. (2010), Park & Dang (2010), and Gujarathi & Ma (2011), among others.

Browning first defined the design structure matrix to deal with integration problems by decomposing systems into its subsystems (Browning, 2001). Ulrich and Eppinger (2004) highlighted the significance of the design structure matrix for the management of engineering projects and Engel et al. (2012) applied it for the optimization of systems architecture for adaptability, to name just a few examples. Kreimeyer et al. (2006), on the other hand, came up with the idea that the design of hierarchical product structures with matrices alone is not enough for efficient product development, since customers mostly focus on the functionalities rather than components. This conflict can especially be observed when it comes to the interaction between CAD and CAE departments as designers manly have a component-oriented view on the product while simulation experts rather take a function-oriented perspective. Therefore, they utilized the design structure and domain mapping matrices to integrate components (CAD) and functionalities (CAE). This paper takes a similar approach as it links people, knowledge, and documents in this context.

3 Methodology

The structural complexity management as presented by Lindemann et al. (2008) aims to reveal the underlying system properties by the use of matrices. A design structure matrix (DSM) provides a clear information about the system by decomposing it into its subsystems, noting the relations between the subsystems, and finally anaylsing the matrix (Browning, 2001). While the design structure matrix is restricted to one domain, a domain mapping matrix (DMM) can be used to note the relations between different domains. However, both DSM and DMM are not capable of dealing with complex systems if they stand alone. As presented by Lindemann et al. (2008), a multiple domain matrix (MDM) is the combination of all DSMs and DMMs in a system.

Application of structural complexity management includes four main steps:

1. Information acquisition for direct dependencies
2. Construction of the MDM
3. Deduction of indirect dependencies
4. Application of optimization techniques

For this paper, a case study was conducted with a German automotive supplier with the aim to enhance collaboration between design and simulation departments. Structured interviews were conducted at the mentioned German automotive supplier and the results of the interviews were transferred into a graph with the software Soley Modeler. This paper, however, focuses on the evaluation of the derived data, not on data acquisition. It may have been better to directly transfer the data from the interviews into a MDM. However, this was not possible in this case due to the nature of the research project. Therefore, based on the information in the graph, a MDM was constructed. However, this MDM had a very low degree of connectivity. The degree of connectivity is obtained by dividing the number of the filled cells by the number of all possible cells. As there exists no dependency on the diagonal, the number of possible cells in an n-by-n MDM is n(n-1). As the degree of the connectivity was too low for sensible calculations in this example, indirect dependencies had to be deducted as well.

According to Maurer (2007) there are six ways of extracting data from available data sets in an MDM. It is the conventional way to apply only one of these methods ("The Conventional Method" in section 4). However, in case of the lack of direct dependencies, those methods may be applied separately and overlapped, too ("The Six Deduction Logics" presented by Maurer). **Figure 1** represents all of the six ways for deriving indirect dependencies for a DSM.

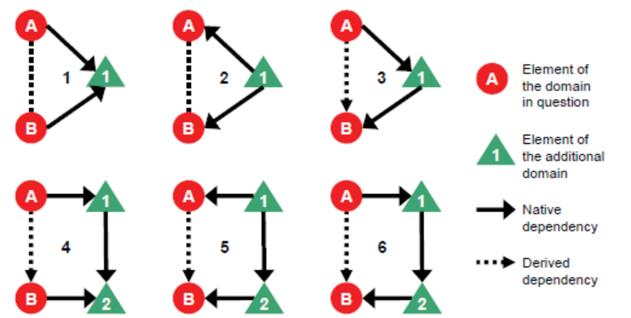


FIGURE 01. *The Deduction Logic for a DSM (Maurer, 2007, p. 85)*

This logic is also valid on DMM level. Hence, it can be taken as a reference for MDM applications. As observed according to Maurer, the dependencies between the elements of the additional domains have to be in the same direction, while the dependencies between the elements of the domain in question and the element of the additional domain may vary.

A third method may be to define all indirect dependencies as bidirectional by only defining the native dependencies in the same direction as unidirectional, e.g. case 3 and 6 in **Figure 1** if the information in the system graph is not very reliable. The indirect dependencies in this case study are deducted not only to the second distance but also to higher distances to obtain a reason-

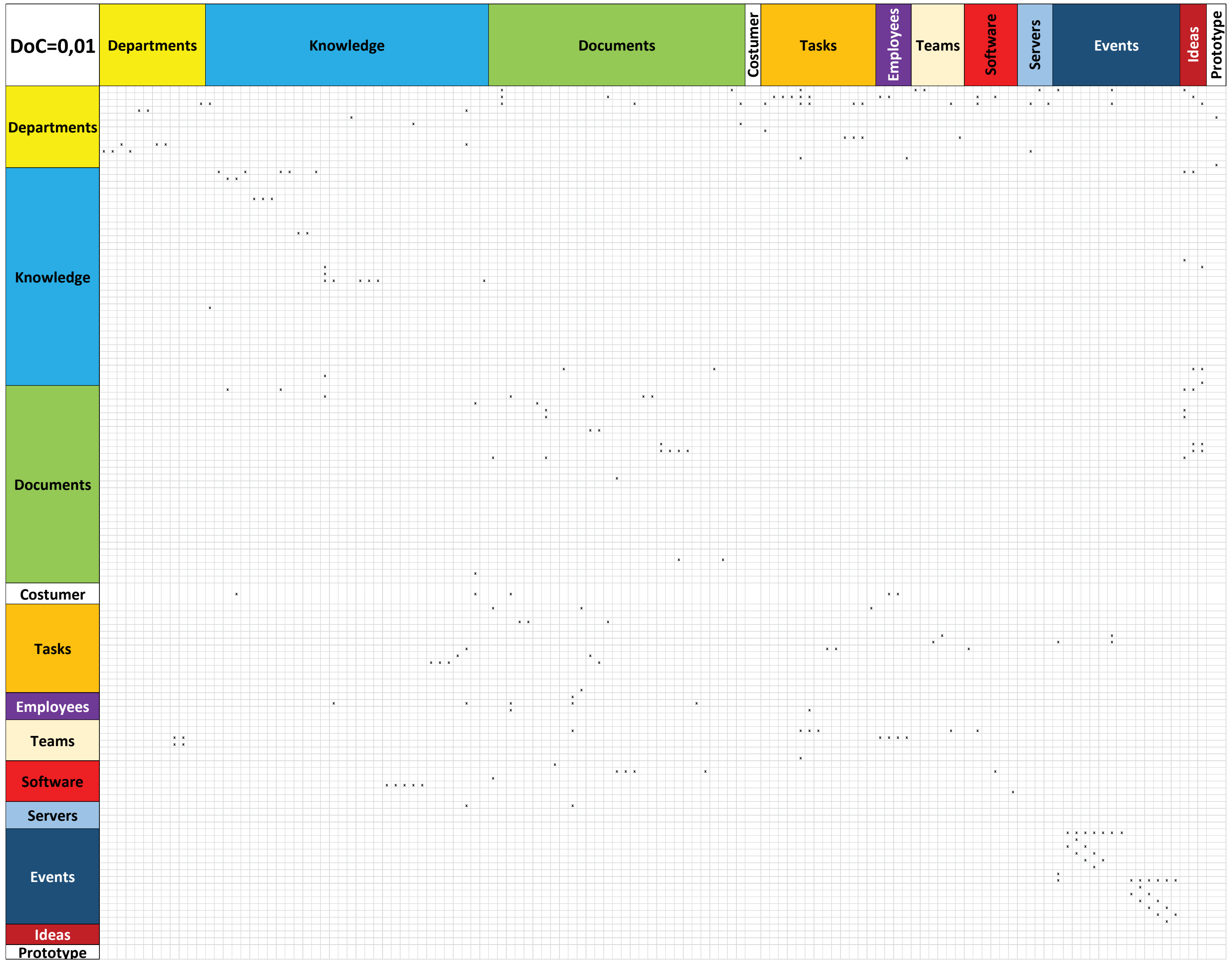


FIGURE 02. *Original MDM with a degree of connectivity of 0.01*

able degree of connectivity and apply standard procedures from structural complexity management like sequencing and clustering.

The methods described above in are applied on the case study's data with two main goals:

- to apply techniques of structural complexity management to enhance the collaboration and communication at the industry partner and
- to further elaborate these methods and gain insights on the influence of the degree of connectivity on the applicability of these methods from an academic point of view.

4 Results

The MDM that resulted from the system graph of the case study includes 135 elements and has a degree of connectivity of 0.01 (**Figure 2**). Due to the confidentiality agreement with the industry partner, only exemplary values are displayed and elements are grouped together without displaying the different items.

As expected, an increase in the degree of connectivity can be obtained by applying the deduction methods. Through the application of the conventional method, a maximum degree of connectivity of 0.12 is obtained (**Figure 3**). Due to the low degree of connectivity and the distribution of it on the matrix, this method cannot be utilized further.

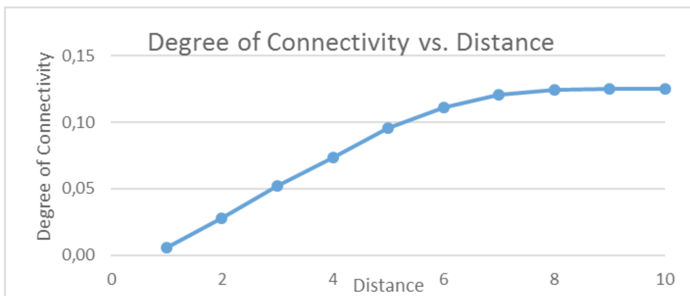


FIGURE 03. *Degree of Connectivity vs. Distance - The Conventional Method*

The application of the second method gives reasonable degrees of connectivity. The calculations have shown that it might be useful to create a MDM with a degree of connectivity around 0.3 - 0.4. Therefore, a matrix with distances up to 4 was used for the second method (**Figure 4**). This MDM can be used for sequencing and clustering purposes.

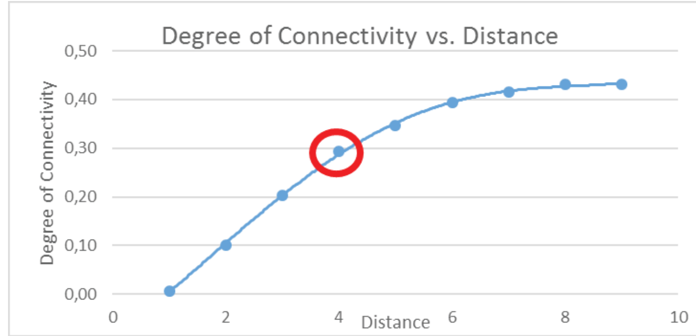


FIGURE 04. *Degree of connectivity vs. distance when applying the six deduction logics*

Due to the same reason, in the third case a MDM up to the distance 3 is created (**Figure 5**). Since this MDM is highly symmetrical, it cannot be used for sequencing purposes.

This leads to the MDM displayed in **Figure 6**, which has a degree of connectivity of 0.34.

After that, we come back to the original question, since the interviews and the MDM were originally not conducted and created for the purpose of inte-

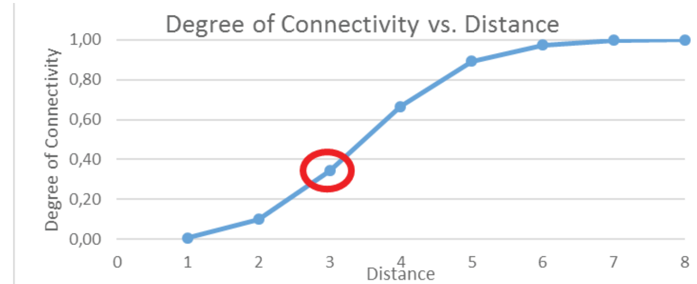


FIGURE 05. *Degree of connectivity vs. distance when using all dependencies*

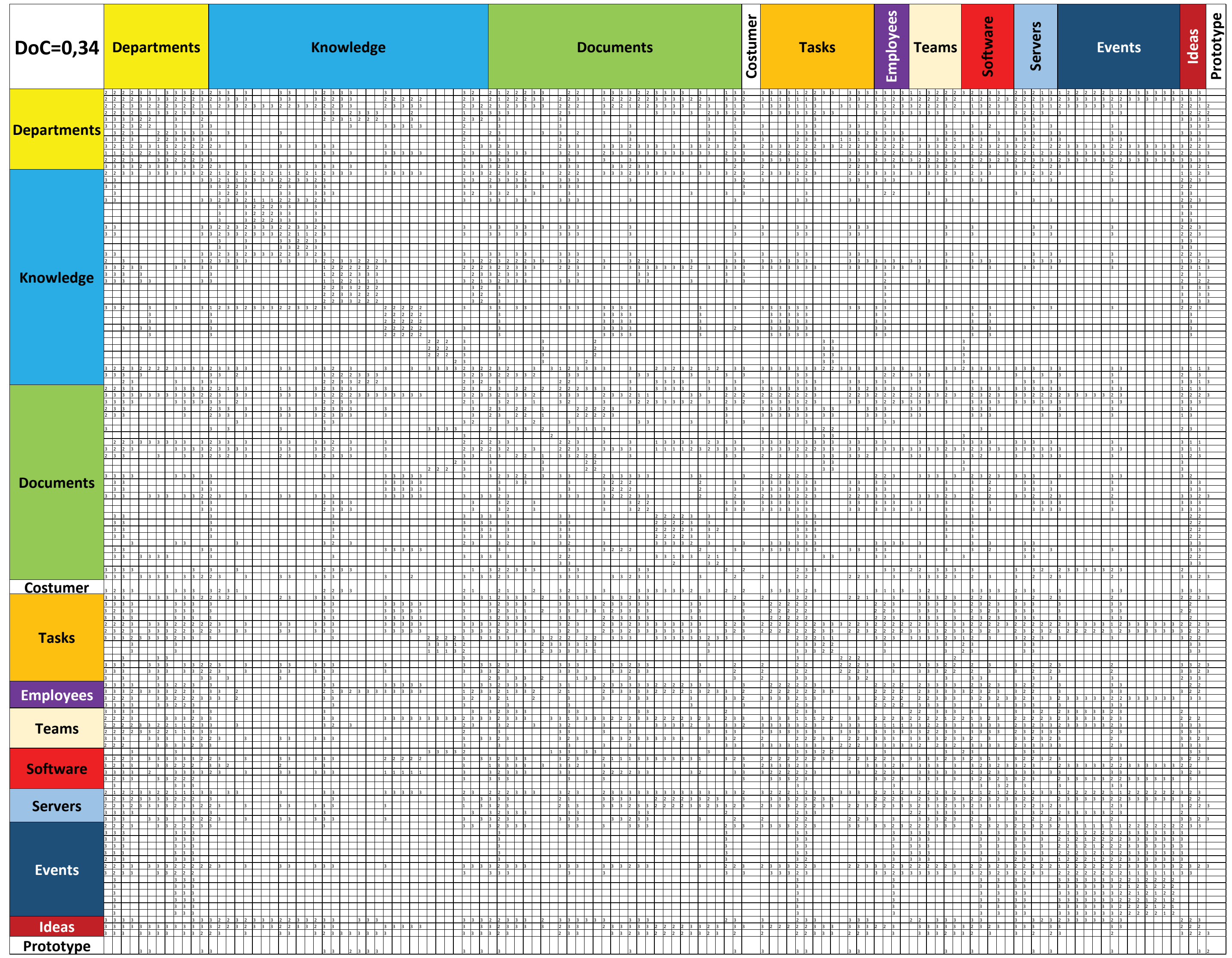


FIGURE 06. *Example for the application of bidirectional and unidirectional dependencies up to distance 3*

grating simulation in the product development process, all elements in the MDM that are not involved in the integration of simulation in the product development, have to be deleted. As the directions in the graph are not very reliable, the MDM constructed through the third method was considered in this case. For this purpose, the minimum distance at which each element either affects the simulation and design departments or is affected by them, was determined for each element. As seen in **Figure 7**, every element is somehow related with the design and simulation departments at a distance of 4. Twelve elements were deleted from the MDM, as they do not fully serve for the integration purpose.

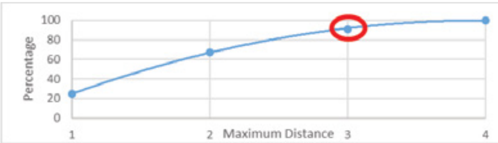


FIGURE 07. *Percentage of elements with a dependency to design or simulation departments vs. maximum distance*

Figure 8 is a clustering example in the domain of knowledge through the application of the third method. The increase in the degree of connectivity compared to the beginning (0.01 to 0.34) has enabled the creation of the clusters.

Figure 9 shows a sequencing example after the application of the second method. The symmetrical relations are colored with red to indicate why no further sequencing is possible.

5 Discussion

The MDM in the case study consists of 135 elements and 11 domains, which means that 18,090 decisions had been made when creating the grapgh in the Soley Modeler. However, one can quickly realize that some direct connections may be missing in the MDM. For example, the design department and CAD data should have been directly connected. However, there is no direct dependency between them in the MDM. This is probably due to the fact that the interview results were first modelled in the Soley Modeler and some first degree connections were modelled as 2nd and maybe 3rd degree connections because it is difficult to model so many direct connections in Soley. Then this data was converted into the matrix form. This situation once again stresses the importance of the verification of the acquired data through interviews since the quality of the final results highly depends on the quality of the original data. Although the optimal degree of connectivity is unknown, this research has shown that a degree of connectivity around 0.3 and 0.4 is suitable for the application of the specific methods of sequencing and clustering. Very low degrees of connectivity can be increased by the use of distance matrices. On the other hand, the already existing knowhow can easily verify the application of this methodology.

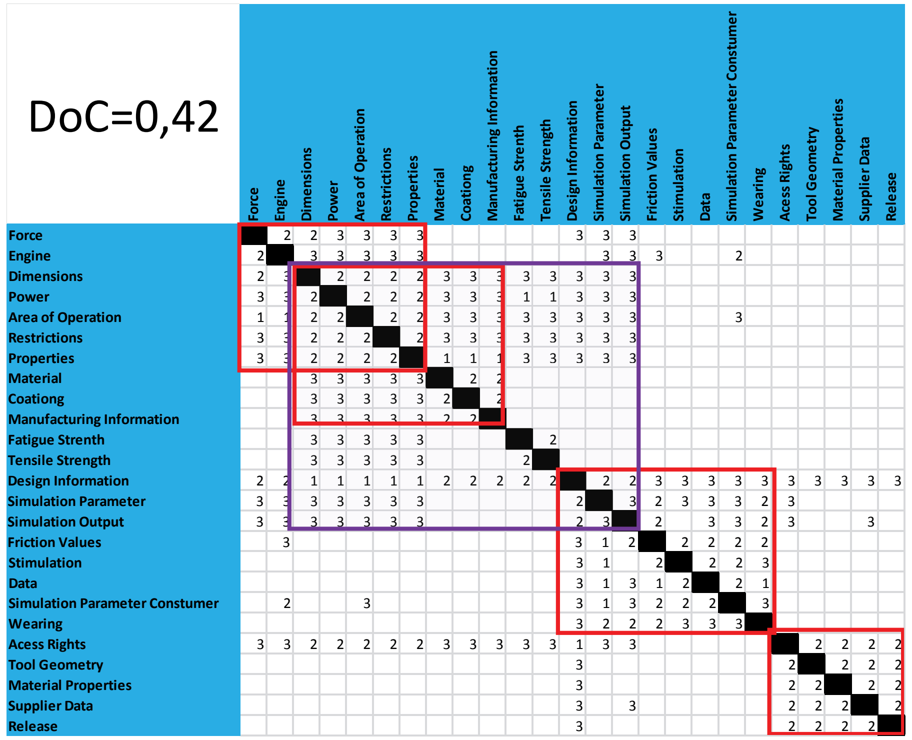


FIGURE 08. *Clustering after the application of the third method for the domain of knowledge*

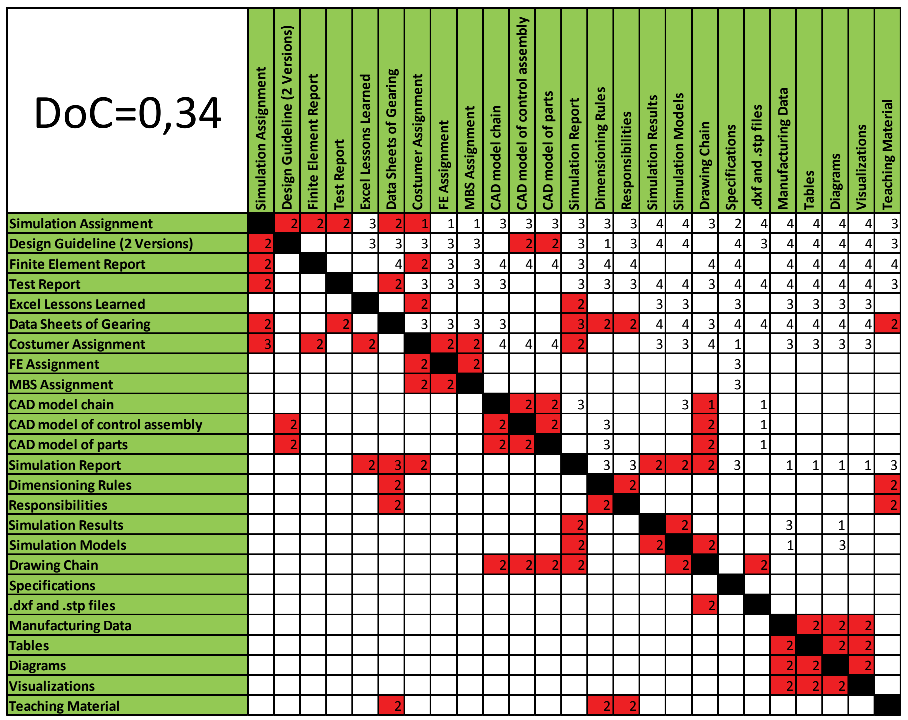


FIGURE 09. *Sequencing example of documents with highlighted bidirectional relations*

For example, one cluster includes CAD-related data like CAD model of control assembly, CAD model of parts, .dxf and .stp files, and CAD model chain. Another cluster example includes data sheets of gearing, design guideline (2 versions), finite element report, simulations assignment, drawing chain, simulation models, simulation report and excel lessons learned. These clusters are sensible and fit to the actual working situation at the industry partner. The same situation is also valid for the sequencing example. Simulation order, simulation order for FEA and MBS, CAD models, simulation results, and technical drawings follow each other, as they should.

When regarding these results, it seems questionable whether the approach really results in new clusters or workflows, which could not have been derived without matrix techniques. What it can proof, however, is the importance of certain elements like the Simulation Assignment in **Figure 9**. This provides a starting point for improvement, which can be very helpful as the many relations between the different elements make it hard to decide, which elements can be a fruitful point for improvement.

6 Conclusion and Outlook

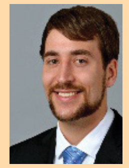
Overall, in this research a new methodology to deal with very low degrees of connectivity, unreliable data, and unnecessary input has been presented. Indirect dependencies are deducted both through the use of the six deduction logics presented by Maurer and considering all directions. The first one was used for sequencing purposes while the later one is used for removing the unnecessary data and clustering purposes.

What the case study cannot provide are general rules for the relationships between the distance and the degree of connectivity for instance. Therefore, the methodology should be applied on further and more complex case studies in order to check its validity and to further elaborate the used metrics.

Acknowledgements

This work is supported by the Bavarian Research Foundation (BFS) within the scope of the Bavarian research project for "efficient product and process development by knowledge based-simulation" FORPRO² (AZ 1071-13).

authors



Sebastian Schweigert is a Research Associate with the Chair of Product Development. Since June 2015 he has been working on his PhD in the field of CAD-CAE integration. Before his PhD, he studied mechanical engineering at the Technical University of Munich for both his bachelor and his master degree. This included an exchange semester at the Nanyang Technological University, Singapore and an internship at Brainlab Inc. as well a master thesis at Siemens.

Mesut Çavuşoğlu is currently a graduate student at the Technical University of Munich. After finishing his bachelor's degree in mechanical engineering at the Bo aziçi University in Istanbul, he started his master's degree in mechanical engineering and management in 2015. During his master studies, he tries to excel himself in product development processes. He also wrote a semester thesis at the Institute of Product Development on the same topic.

Udo Lindemann is of the Chair of Product Development at the Technical University of Munich. Today he is a member of the Academic Senate of the Technical University Munich. He is co-publisher of the German journal "Konstruktion" and co-editor of several international journals. Since the initiation of the Design Society, he has been an active member; from 2007 to 2010, he served as its President. In addition, he is an active member of a number of scientific societies and other organizations. 2008 he became a member of the German Academy of Science and Engineering

references

Assouroko, I., Ducellier, G., Belkadim, F., Eynard, B., & Boutinaud, P. (2010). Improvement of engineering design and numerical simulation data exchange based on requirements deployment: a conceptual framework. Proceedings of the 7th International Product Lifecycle Management Conference, Bremen.

Browning, T. R. (2001). Applying the design structure matrix to system decomposition and integration problems: a review and new directions. Engineering Management, IEEE Transactions on, 48(3), 292-306.

Deubzer, F., Herfeld, U., Kreimeyer, M., & Lindemann, U. (2005). A structured holistic approach for the integration of CAD and CAE environments. Paper presented at the ProSTEP iViP Science Days 2005-Cross Domain Engineering.

Engel, A., Reich, Y., Browning, T.R., Schmidt, D.M., 2012. Optimizing system architecture for adaptability. Proceedings of INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012 May 21 - 24, 2012.

Forsen, J., & Hoffmann, R. (2002). Assoziative FE-Netze in der Karosserieentwicklung. Düsseldorf: VDI-Verlag.

Gujarathi, G., & Ma, Y.-S. (2011). Parametric CAD/CAE integration using a common data model. Journal of Manufacturing Systems, 30(3), 118-132.

Hirz, M., Dietrich, W., Gfrerrer, A., & Lang, J. (2013). Integrated computer-aided design in automotive development. Book). http://books. google. com/books.

Kreimeyer, M., Deubzer, F., Herfeld, U., & Lindemann, U. (2005). Holistic Integration of CAD and CAE: Analysis and Combination of Diverse Current Approaches In: Ekinoviæ: S.

Kreimeyer, M., Herfeld, U., Deubzer, F., Dequidt, C., & Lindemann, U. (2006). Function-driven product design in virtual teams through methodical structuring of requirements and components. Paper presented at the ASME 8th Biennial Conference on Engineering Systems Design and Analysis.

Lindemann, U., Maurer, M., & Braun, T. (2008). Structural complexity management: an approach for the field of product design: Springer Science & Business Media.

Maier, A. M., Kreimeyer, M., Lindemann, U., & Clarkson, P. J. (2009). Reflecting communication: a key factor for successful collaboration between embodiment design and simulation. Journal of Engineering Design, 20(3), 265-287.

Maurer, M. S. (2007). Structural awareness in complex product design. Universität München.

Park, H.-S., & Dang, X.-P. (2010). Structural optimization based on CAD–CAE integration and metamodeling techniques. Computer-Aided Design, 42(10), 889-902. doi: http://dx.doi.org/10.1016/j.cad.2010.06.003

Schumacher, A., Merkel, M., & Hierold, R. (2002). Parametrisierte CAD-Modelle als Basis für eine CAE-gesteuerte Komponentenentwicklung.

Ulrich, S.D., Eppinger, K.T., 2004. Product Design and Development, 3rd ed. McGraw-Hill, New York, pp 331-335.