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ANALYZING COMMUNICATION DEPENDENCIES IN PRODUCT DEVELOPMENT USING THE DESIGN STRUCTURE MATRIX

Clemens Hepperle[1], Anja M Maier[2], Matthias Kreimeyer[1], Udo Lindemann[1] and P John Clarkson[2]

[1]Institute of Product Development, Technische Universität München
[2]Engineering Design Centre, University of Cambridge

Keywords: communication, product development, organization design, concurrent engineering, linking factors, change propagation

1 INTRODUCTION

For the design and development of complex technical products, communication between staff who work across functional and organizational boundaries plays an important role. However, the quality of communication is hard to measure. One method to assess communication is the *Communication Grid Method* (CGM) [1, 2]. The CGM is a maturity-based form of self-assessment to reflect on different factors influencing communication in product development. The factors belong to manifold areas influencing communication, such as the organizational structure, the company culture, teamwork, different aspects of information transfer and availability as well as several aspects of product representations. In a number of CGM-based studies, designers and managers from a number of industry sectors gave insight into their communication situation by scoring the current state of 24 factors influencing communication. To do so, the participants chose between four maturity levels, adapted from the learning types by Argyris & Schön [3], for each factor influencing communication. This data were used in the presented study to explore interrelations between the different factors describing communication. Within the correlations, a number of structural patterns were ascertained.

2 OBJECTIVES AND ANALYSIS PROCEDURE

Research in this paper was performed with two objectives in mind: Firstly, to explore singular linkages between pairs of individual factors influencing communication, and, secondly, to elicit a network of connections between the whole set of factors. Analysis is based on the premises that individual linkages have to be judged in context and individual factors are not orthogonal to each other (*i.e.* independent of each other).

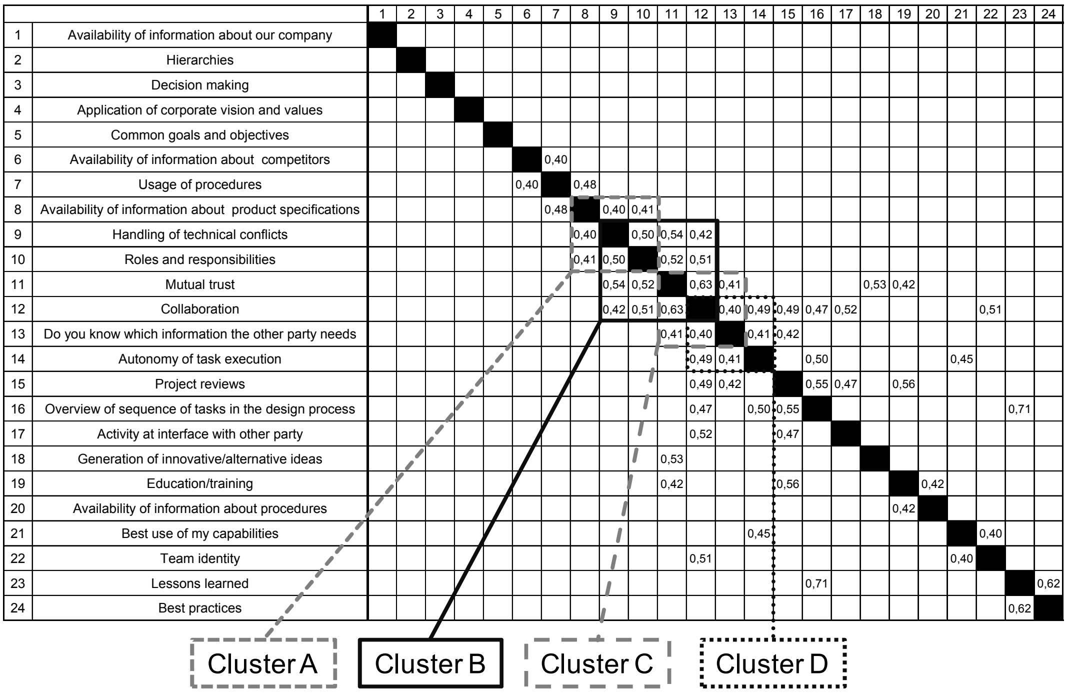
To meet the objectives, scores from design engineers and managers on the current state of 24 factors influencing communication were taken, deploying the CGM at five companies. Using Kendall´s *tau-b* rank correlation coefficient, a correlation analysis was performed with data from max. 38 participants on all 24 different factors. The correlation matrix indicates relations between pairs of factors, also called singular linkages in this paper. The complete correlation matrix was used as a basis for further analyses, using Design Structure Matrix (DSM) techniques. In particular, clusters and cycles were identified. Clusters represent a set of factors which are completely linked among each other. Based on these clusters, groups of factors which offer a high concentration of linkages could be determined. Cycles show that changing the current state of a certain factor might lead to further unexpected changes on factors not directly linked with the originally changed factor.

3 ANALYSIS RESULTS OF COMMUNICATION DEPENDENCIES

The structure of a correlation matrix [4] as generated through the correlation analysis is similar to that of a DSM. Techniques appropriate for DSM analysis and optimization [5] can be used to gain further insight into results from the correlation analysis. To perform analyses in the context of a DSM, the software tool Loomeo [6] was used.

However, the correlation matrix provides symmetric correlation coefficients for each pair of factors. Thus, the Design Structure Matrix would be a symmetric, completely filled in matrix. Yet, in this study, many of the correlation coefficients only represented weak linkages. In our DSM, only those correlations characterized by a coefficient $\geq |0.40|$ (moderate and high correlations) that were

statistically significant at a level of $p < 0.05$ were considered. This explains the rather sparse population of the matrix.
To visualize clusters of factors that are completely linked among each other, the first step was to switch the rows and, as the matrix is a DSM, simultaneously also the columns. Again, only correlations with a coefficient value of ≥ |0.40| were taken into consideration. Figure 1 shows one example of restructuring the original correlation matrix. In this example, four clusters of factors that are completely linked among each other are highlighted (clusters A to D).



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Availability of information about our company																								
2	Hierarchies																								
3	Decision making																								
4	Application of corporate vision and values																								
5	Common goals and objectives																								
6	Availability of information about competitors							0,40																	
7	Usage of procedures						0,40		0,48																
8	Availability of information about product specifications							0,48		0,40	0,41														
9	Handling of technical conflicts								0,40		0,50	0,54	0,42												
10	Roles and responsibilities								0,41	0,50		0,52	0,51												
11	Mutual trust									0,54	0,52		0,63	0,41					0,53	0,42					
12	Collaboration									0,42	0,51	0,63		0,40	0,49	0,49	0,47	0,52					0,51		
13	Do you know which information the other party needs											0,41	0,40		0,41	0,42									
14	Autonomy of task execution												0,49	0,41			0,50					0,45			
15	Project reviews												0,49	0,42			0,55	0,47		0,56					
16	Overview of sequence of tasks in the design process												0,47		0,50	0,55								0,71	
17	Activity at interface with other party												0,52			0,47									
18	Generation of innovative/alternative ideas											0,53													
19	Education/training											0,42				0,56					0,42				
20	Availability of information about procedures																			0,42					
21	Best use of my capabilities														0,45								0,40		
22	Team identity												0,51									0,40			
23	Lessons learned																0,71								0,62
24	Best practices																							0,62	

Figure 1. Clusters of factors which are completely linked among each other

By further restructuring the matrix, four more clusters in addition to clusters A to D were highlighted:

- Cluster E: Collaboration; Autonomy of task execution; Overview of sequence of tasks in the design process
- Cluster F: Collaboration; Overview of sequence of tasks in the design process; Project reviews
- Cluster G: Collaboration; Project reviews; Activity at interface with other party
- Cluster H: Collaboration; Project reviews; Do you know which information the other party needs

Taking the DSM in Figure 1 as the basis, the next step was to further assess those linkages that were missing to create complete clusters (bearing in mind that the original correlations were not zero). That way it was possible to illustrate that more factors than those involved at a correlation coefficient ≥ |0.40| and a significance of $p < 0.05$ form a complete cluster. Nine factors among the 24 factors offer a high concentration of linkages. These nine factors are mentioned in Figure 1 and range from 'availability of information about product specifications' to 'overview of sequence of tasks in the design process'. The result was cross-checked with the results of a hierarchical cluster analysis [4]. When matching the results, seven of the nine factors showing a high linking degree among each other elicited through restructuring the DSM were also found to be closely linked as elicited through the hierarchical cluster analysis.

Finally, the DSM was the basis to calculate cycles among the 24 factors influencing communication. A cycle in this context is defined as a loop of linked factors. Overall, 203 cycles were identified, incorporating 13 of the 24 factors. The factor 'collaboration' appeared most often in the cycles, being part of 197 cycles. The linkage between 'do you know which information the other party needs' and 'mutual trust' was the most appearing linkage as it is part of 92 cycles. The cycles show that changing a certain factor might not only change the factor directly linked but also cause unintended propagations to factors not directly linked with the factor changed in the first instance.

4 IMPLICATIONS

Design managers who are confronted with problems in their processes, naturally try to understand where these problems originate from in order to find a solution. However, thinking through these problems can be time-consuming and potentially difficult without a point of departure. Results in this paper show that using the DSM to elicit patterns of connections between factors influencing communication can be a starting point for reflection and action on a particular process. Furthermore, increasing transparency into the network of connected factors impacting on communication in product development can reduce uncertainty. A cluster of factors, for example, can alert engineers and managers when changing one factor, to also pay attention to other directly linked factors. Looking at Cluster A in Figure 1, for example, whilst trying to resolve technical conflicts, one could start by making sure that data on product specifications is available and roles and responsibilities are clearly defined. Cycles lead to the detection of indirect linkages and alert decision makers to another potential propagation path of changes.

5 CONCLUSIONS AND FURTHER WORK

A DSM, populated by statistical correlations between factors influencing communication, sheds light on communication dependencies in product development. The correlation analysis only described singular linkages for the 24 selected factors influencing communication in product development. In contrast, analyses using the DSM as a basis show that there is a particular structure to the 24 factors.

As the input for the DSM was a symmetric correlation matrix, the chains of cause and effect of the linkages are not given. Thus, more information about the correlations has to be carried out to determine which linkages are only unidirectional and which linkages are bidirectional. For some of the linkages this next step was already carried out on the basis of an extensive literature research on dependencies among the 24 selected factors influencing communication. Despite the limitation that the chains of cause and effect were not considered, the results show that using the DSM is a viable and valuable option to structure communication and thus to enhance understanding of pertinent organizational issues in product development. Sensitivity of classifying the correlations as weak or strong linkages remains to be considered. So far, the work has been carried out, using correlation coefficients $\geq |0.40|$ at a significance level of $p < 0.05$, as commonly done. Thus, the actual robustness of the structural features can be confirmed.

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Contact: Clemens Hepperle
Technische Universität München
Lehrstuhl für Produktentwicklung
Boltzmannstr. 15
85748 Garching
Germany
Phone: +49 (0)89 – 289 151 32
Fax: +49 (0)89 – 289 151 44
clemens.hepperle@pe.mw.tum.de
www.pe.mw.tum.de

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Analyzing Communication Dependencies in Product Development Using the Design Structure Matrix

Clemens Hepperle[1], Anja M Maier[2], Matthias Kreimeyer[1], Udo Lindemann[1] and P John Clarkson[2]

[1]Technische Universität München, Institute of Product Development, Germany

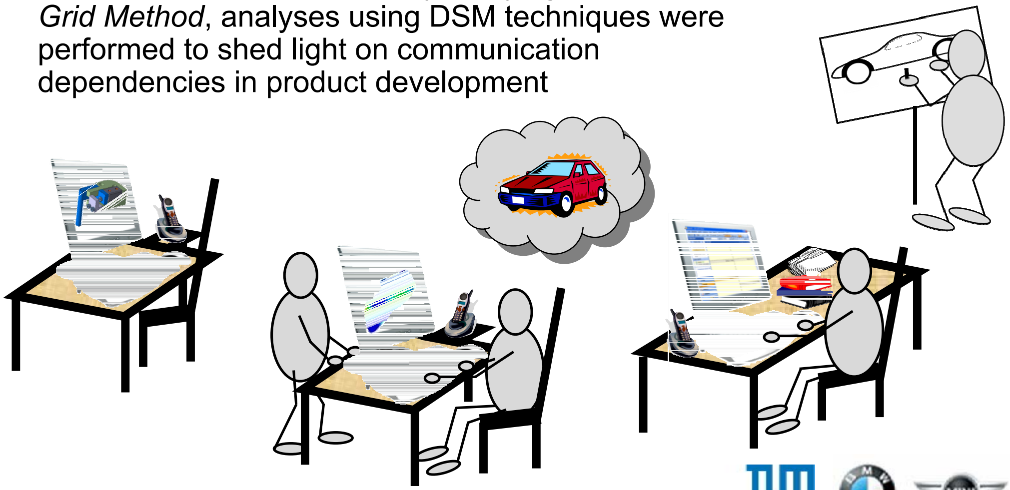
[2]University of Cambridge, Engineering Design Centre, UK

Agenda

- Introduction – communication in product development
- Data collection using the 'Communication Grid Method' (CGM)
- Web of linkages among factors influencing communication
- Analysis of web of linkages as a whole using DSM techniques
- Implications for collaborative design
- Conclusions and future work

Introduction – communication in product development

- Communication between staff in product development plays an important role for the design of complex products
- Communication in product development can be defined in manifold ways
- Communication is hard to measure
- → Based on data collected by applying the *Communication Grid Method*, analyses using DSM techniques were performed to shed light on communication dependencies in product development



Communication Grid Method (CGM)

- The 'Communication Grid Method' is a method to assess communication in product development incorporating manifold factors
- Following structure shows the concept of deriving these factors

***Different areas** having influence on communication in product development:*

- Organisational structure
- Organisational culture
- Teamwork → Collaboration; Common goals and objectives; Team identity; …
- Reflection within team
- Personal development
- Awareness
- Information transmission/handling
- Availability of information … → … about our company; … about competitors; … about procedures; … about product specifications; … about new technologies
- Media of communication
- Expression of the product
- Requirements

*Subdivision of areas into **detailed factors**:*

Collaboration
Common goals and objectives
Team identity
…

… about our company
… about competitors
… about procedures
… about product specifications
… about new technologies

Data collection using the *Communication Grid Method* (CGM)

- ‘Levels of maturity’ for communication factors (levels A to D)
- Levels A to D are ordinal scaled
- Current communication situation recorded by ‘Current scores’

Teamwork

Please answer for your project team

	Levels of maturity					
Factors	**A**	**B**	**C**	**D**	**Current score**	**Desired score**
Collaboration	Everyone looks solely after his or her tasks	Collaboration happens only if asked for in order to fulfil tasks	Collaboration happens proactively in order to learn from others and improve own approaches	Collaboration is constructive, happens regularly whenever necessary and there is continuous effort to improve it	[ ]	[ ]
Common goals and objectives	Not known. No thinking about it	Known but everyone follows just his or her own goals	Known and sometimes consideration about the way common goals can be reached through working together	Entirely clear and identification with it which is expressed in communication and continuous effort to assess and adjust goals and objectives and the way to each them	[ ]	[ ]
Team identity	There is none and it is not seen as necessary	Small groups form depending on the task and these groups get their identity through the tasks	Attitudes with respect to team identity are continuously reflected upon in order to find a common denominator	There is a strong sense of belonging to the team and continuous reflection on how team identity can be kept up and strengthened for the project	[ ]	[ ]

Comments

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Data collection using the *Communication Grid Method* (CGM)

- Five application cases in
  - aerospace industry
  - automotive industry
  - information technology industry
- Seven or eight engineers or managers per application case (overall 38)
- 24 factors appearing in at least four of five application cases selected for further analyses
- Rank-ordered data applicable for statistical data analyses
- Data for current communication situation used for further analyses on communication dependencies in product development

Web of linkages among factors influencing communication

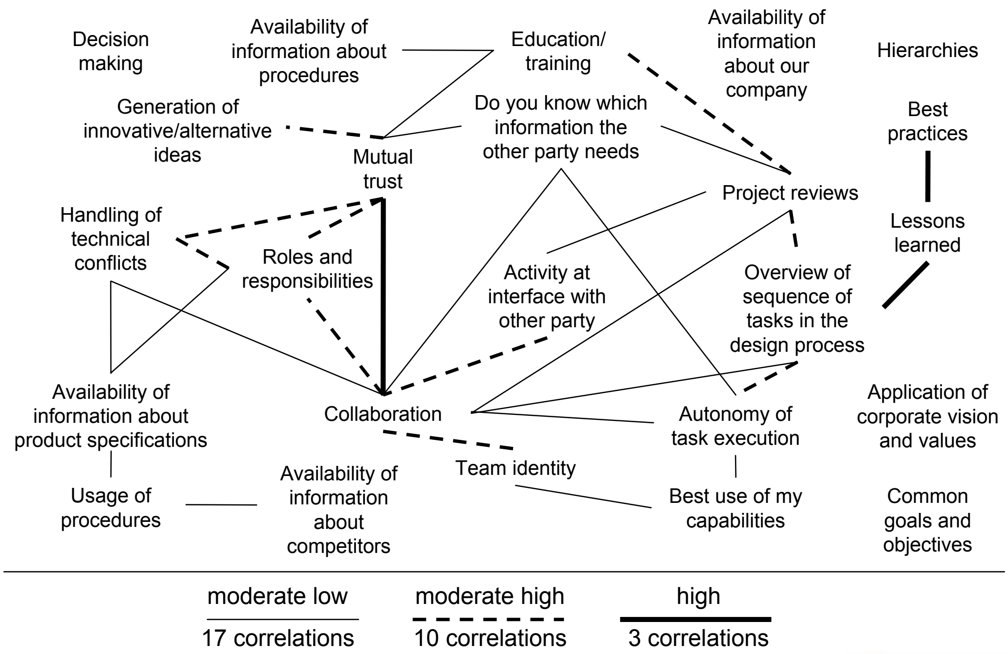
Objectives:

- Identifying singular linkages among couples of factors influencing communication in product development
- Understanding the network of factors influencing communication in product development as a whole

Procedure:

- Calculation of Kendall's *tau-b* correlation coefficients by using data collected via the *Communication Grid Method*
- Excluding correlations not statistically significant at a level of $p < 0.05$
- Excluding correlations characterized by a coefficient $< |0.40|$
- Correlations characterized as follows were used for further analyses:
  - moderate low correlations ($|0.40| \leq$ correlation coefficient $< |0.50|$)
  - moderate high correlations ($|0.50| \leq$ correlation coefficient $< |0.60|$)
  - high correlations ($|0.60| \leq$ correlation coefficient $< |0.80|$)

Web of linkages among factors influencing communication



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Analysis of web of linkages as a whole using DSM techniques

- To meet the objective of understanding the network of factors as a whole, DSM techniques were applied (using the software-tool Loomeo) on the basis of the adapted correlation matrix
- The correlation matrix is symmetric, *i.e.* the chains of cause and effect of the correlations cannot be deduced
- All considered correlations show positive coefficients
- Building clusters in the matrix shows sets of factors completely linked among each other
- Cycles among the 24 considered factors show that changing the current state of a certain factor might lead to further unexpected changes on factors not directly linked with the originally changed factor

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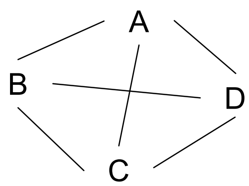
Analysis – Identifying clusters by rearranging correlation matrix

- A cluster is a set of factors completely linked among each other
  Example: cluster consisting of four factors A, B, C and D:

  factor A correlates with factor B
  factor B correlates with factor C
  factor C correlates with factor D
  factor D correlates with factor A
  factor A correlates with factor C
  factor B correlates with factor D



- By shifting rows and columns of correlation matrix, 'clusters' are visualized
- Clusters indicate groups of factors highly dependent among each other
- Among the 24 factors, eight clusters were identified

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Analysis – Identified clusters A to D in correlation matrix

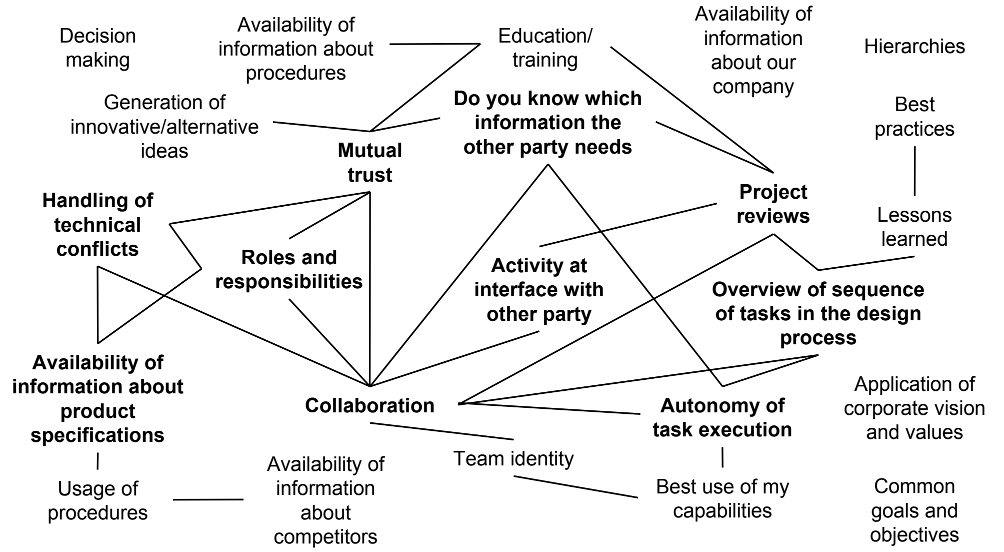
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Availability of information about our company	■																							
2	Hierarchies		■																						
3	Decision making			■																					
4	Application of corporate vision and values				■																				
5	Common goals and objectives					■																			
6	Availability of information about competitors						■	0,40																	
7	Usage of procedures						0,40	■	0,48																
8	Availability of information about product specifications							0,48	■	0,40	0,41														
9	Handling of technical conflicts								0,40	■	0,50	0,54	0,42												
10	Roles and responsibilities								0,41	0,50	■	0,52	0,51												
11	Mutual trust									0,54	0,52	■	0,63	0,41					0,53	0,42					
12	Collaboration									0,42	0,51	0,63	■	0,40	0,49	0,49	0,47	0,52					0,51		
13	Do you know which information the other party needs											0,41	0,40	■	0,41	0,42									
14	Autonomy of task execution												0,49	0,41	■		0,50					0,45			
15	Project reviews												0,49	0,42		■	0,55	0,47		0,56					
16	Overview of sequence of tasks in the design process												0,47		0,50	0,55	■							0,71	
17	Activity at interface with other party												0,52			0,47		■							
18	Generation of innovative/alternative ideas											0,53							■						
19	Education/training											0,42				0,56				■	0,42				
20	Availability of information about procedures																			0,42	■				
21	Best use of my capabilities														0,45							■	0,40		
22	Team identity												0,51									0,40	■		
23	Lessons learned																0,71							■	0,62
24	Best practices																							0,62	■

Cluster A | Cluster B | Cluster C | Cluster D

Analysis – Further clusters and factors characterized by a high linking degree

- Restructuring the DSM further sheds light on four more clusters:
  - Cluster E: Collaboration; Autonomy of task execution; Overview of sequence of tasks in the design process
  - Cluster F: Collaboration; Overview of sequence of tasks in the design process; Project reviews
  - Cluster G: Collaboration; Project reviews; Activity at interface with other party
  - Cluster H: Collaboration; Project reviews; Do you know which information the other party needs
- Assessing those linkages that were missing to create complete clusters (bearing in mind the original correlations were not zero), yields nine factors that show a high linking degree among each other:
  - Availability of information about product specifications
  - Handling of technical conflicts
  - Roles and responsibilities
  - Mutual trust
  - Collaboration
  - Do you know which information the other party needs
  - Autonomy of task execution
  - Project reviews
  - Overview of sequence of tasks in the design process

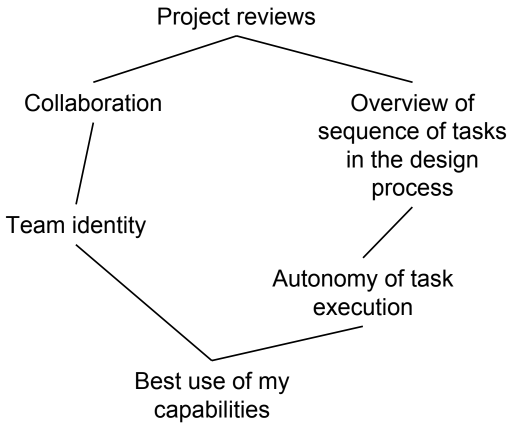
Analysis – The eight identified clusters in the web of linkages



10 factors are part of clusters and are highlighted in **bold**

Analysis – Identifying cycles in the web of linkages

- A cycle in this context is defined as a loop of correlating factors
- The length of a cycle is defined as the number of factors being part of a cycle (the example shows a cycle with the length 6 in the web of the 24 considered factors)
- Cycles indicate change propagations in the web of linkages
- Changing the status of a certain factor might not only change the factor directly linked with the originally changed factor, there might be further unintended changes on factors, not directly with the originally changed factor



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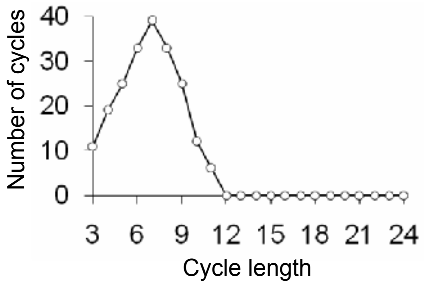
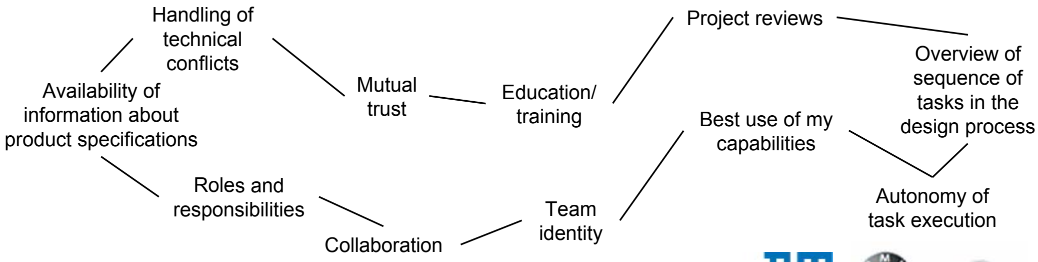
Analysis – Identifying cycles in the web of linkages – Results and statistics

- Overall 203 cycles detected among the 24 considered factors (distribution cycles per cycle length see right figure)
- 13 of the 24 considered factors are part of cycles
- Most cycles occurring consist of seven factors (cycle length 7)
- Six 'longest' cycles consist of 11 factors (example see figure)





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Analysis – Identifying cycles in the web of linkages – Results and statistics

- Following five linkages occur most often in the 203 cycles:
  - Do you know which information the other party needs ↔ Mutual trust: part of 92 cycles
  - Do you know which information the other party needs ↔ Autonomy of task execution: part of 86 cycles
  - Mutual trust ↔ Education/training: part of 85 cycles
  - Project reviews ↔ Education/training: part of 85 cycles
  - Project reviews ↔ Overview of sequence of tasks in the design process: part of 83 cycles
- Following five factors occur most often in the 203 cycles:
  - Collaboration (part of 197 cycles)
  - Mutual trust (part of 171 cycles)
  - Project reviews (part of 157 cycles)
  - Do you know which information the other party needs (part of 146 cycles)
  - Autonomy of task execution (part of 125 cycles)

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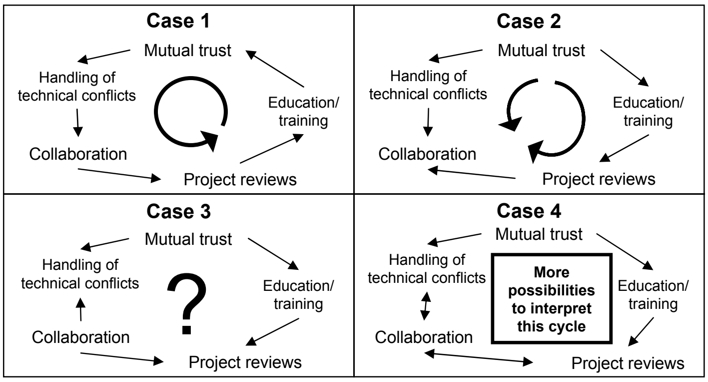
Analysis – Identifying cycles in the web of linkages – Interpretation of cycles

- Chains of cause and effect of the correlations cannot be deduced from the symmetric correlation matrix
- No final interpretation of the cycles can be drawn. Following cycle of a length of 5, for example, could be interpreted in manifold ways, as the cases 1 to 4 show
- Arrow between factors shows possible chains of cause and effect



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Implications for collaborative design

- For design managers thinking through problems in the design process can be time-consuming and it can be difficult to find a point of departure
- Results in this article show that using the DSM to elicit patterns of connections between factors influencing communication can be a starting point for reflection and action on a particular process
- Results achieved by using DSM techniques increase transparency of the network of connected factors influencing communication in product development and thereby reduce uncertainty in design processes
- Clusters of factors can alert engineers and managers when changing one factor, to also pay attention to other directly linked factors
- Cycles lead to the detection of indirect linkages and alert decision makers to another potential propagation path of changes

Conclusions

- Data collected by applying the *Communication Grid Method* in five case studies in automotive, aerospace and information technology industry allowed a Kendall's *tau-b* correlation analysis
- The Kendall's *tau-b* correlation matrix considering 24 factors influencing communication in product development was used for further analyses using DSM techniques, shedding light on the web of correlating factors as a whole
- In particular, two DSM techniques were used:
  - **Identification of clusters:** Analysing the different clusters shed light on a group of nine factors showing a high linking degree among each other. Clusters show that changing the status of a certain factor might have impact on many other factors being part of the cluster. Reliability of results is indicated by parallel performed 'Hierarchical cluster analysis'.
  - **Identification of cycles:** Cycles represent loops of correlating factors. 203 cycles were detected among the 24 considered factors. 'Mutual trust', 'collaboration' and 'project reviews' occur frequently. Cycles show potential change propagation paths.

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Future work

- Collecting more data in empirical case studies in order to allow consideration of more than 24 factors influencing communication in product development in the analyses
- Incorporating knowledge about existence and directions of correlations (chains of cause and effect) into the analyses using DSM techniques. This can be achieved by an extensive literature research (already performed for correlations characterized by coefficients ≥ $|0.50|$)
- Including linkages in the DSM analyses generally supported by literature but not detected by performed correlation analyses
- Further information about chains of cause and effect of correlations can be used to interpret clusters and cycles in more detail