EVALUATING THE NEED FOR TRACEABILITIY IN PRODUCT DEVELOPMENT: A PRILIMINARY STUDY

Koehler, Nico; Naumann, Thomas; Vajna, Sandor
Otto-von-Guericke University Magdeburg, Germany

Abstract

This paper presents a novel approach on how to evaluate the need for further traceability support in integrated product development. For the purpose of an descriptive study, a universal questionnaire is developed in order to determine this need for traceability. The questionnaire focuses on measuring, from an engineer's point of view, the ability to follow engineering objects from the origin to the use in the final product. However, considering only the dimension of traceability isolated from its context is not sufficient. Thus, we extended the questionnaire with two new dimensions, one considering the problem solving and the other one considering complexity. Starting from theory based constructs, for each dimension we developed specific and applicable items. With the help of those items related to all three dimensions: (1) traceability, (2) problem solving and (3) complexity, we are able to statistically determine the need for traceability support in integrated product development.

Keywords: Complexity, Traceability, Problem Solving, Questionnaire Design

Contact:
Nico Koehler
Otto-von-Guericke University Magdeburg
Information Technology and Mechanical Engineering
Germany
koehler.nico@me.com

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

In the past years, companies have struggled to handle the increased complexity of their product development. In order to compete on the market companies focus on reducing product costs, shortening the development process as well as increasing product quality (Vajna et al., 2009). According to Koenigs et al. (2012), trends like rising number of functionalities, modularization and reduction of hardware prototypes have led to a significant increase of Engineering Objects (EOs) and their Engineering Object Relations (EORs) These problems are intensified by the variety of software tools currently used in the industry, which make an integrated product development process even more complicated (Storga, 2004). Therefore, analyzing the impacts of changes of product characteristics across different departments is hardly possible. This results in inconsistent, redundant and non-transparent engineering objects (Brandt et al., 2007). An approach addressing the above mentioned problems from the 1970s focusing on the engineering object relations is traceability (Koenigs et al., 2012).

> Transferred from requirements engineering to the development of mechatronic products, traceability comprises the ability to follow every engineering object with the help of relations from its origin to its use in the final product (Gotel and Finkelstein, 1994).

Subsequently, the aim of this paper is to develop a descriptive study evaluating the need for tracing objects from an engineer's point of view. In order to identify traceability issues, we carried out six in-depth interviews with experts from the early development phase. Based on the expert interviews, we developed a questionnaire that consists of 58 closed-ended questions distributed over four main parts: problem solving (6), complexity (16), traceability (30) and demographic information (6). In addition to the closed-ended questions, every part contains one open-ended question in order to have the possibility to comment that particular part. To measure the attitude of engineers towards traceability we used a five-point Likert scale distinguishing between "strongly disagree" and "strongly agree" (Oppenheim, 1992). Figure 1 shows the four parts of the questionnaire in detail including their corresponding constructs. The questionnaire was developed according to the seven steps to design a survey questionnaire (Gideon, 2012). Additionally, Figure 1 shows the development of the construct variables for each of the four parts based on the research objective. According to the construct variables, the items of the questionnaire were developed. In order to illustrate the implementation of the questionnaire's framework, please find the entire questionnaire in the appendix.

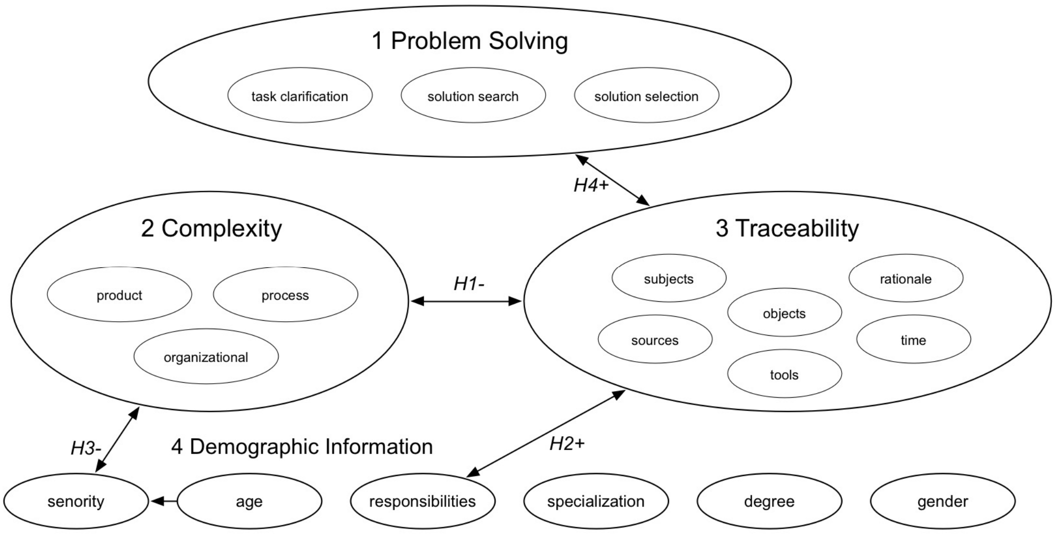

Figure 1. Framework of questionnaire

2 THEORETICAL BACKGROUND

The given definition of traceability focuses on software engineering; however, the concept of traceability is transferable to any system development (Buur and Andreasen, 1989). Generally, traceability represents "a quality factor of designing — a property that product development environment should possess" (Storga, 2004). Transferred from requirements engineering to the development of mechatronic products, traceability comprises the ability to follow every engineering object with the help of relations from its origin to its use in the final product (Gotel and Finkelstein, 1994). Due to its complex mechatronic systems today's product development is especially made for an integrated traceability approach.

The goal is to enable the understanding of semantic relationships within and across different engineering contexts. However, research about traceability in product development is still immature (Ramesh and Jarke, 2001). Especially, the absence of automatic techniques supporting the modeling objects and their relations represents the major drawbacks of traceability: the labor-intensive modeling of traceability information. This is illustrated by the question Storga (2004) arose a decade ago and that is still up-to-date: "Why is the achievement of engineering information traceability in modern highly-automated product development environments, still so difficult?". Therefore, the development of new approaches for trace-recording in product development is the key to handle complexity regarding interdependent relations of engineering objects (Koehler et al., 2014).

In order to measure the need for further traceability support it is not sufficient to consider traceability itself. Especially, the context of traceability is relevant to make a statement for prospective research. Therefore, we completed the questionnaire design by a problem solving as well as a complexity dimension. According to Figure 1 we hypothesize that complexity has a negative correlation with traceability (H1). Problem solving is assumed to have a positive correlation with traceability (H4). Additionally, the demographic information completes the context of traceability. This leads to the hypothesis that the engineer's responsibility has a positive correlation with traceability (H2) whereas seniority has a negative correlation with complexity (H3). Besides the measure of the construct variables, the questionnaire contains statements to evaluate how to handle complexity and traceability in the future more effectively and efficiently. In the following, the construct variables as well as their items are described in detail.

3 METHODOLOGY OF THE QUESTIONAIRE DESIGN

Problem solving as the first dimension of the questionnaire analyzes the ability of product development to solve problems systematically. In order to evaluate problem solving in any product development environment, the problem solving cycle for systems engineering based on Hall adapted by Haberfellner et al. (2012) is used. Accordingly, the constructs of problem solving distinguish between three activities: task clarification, solution search and solution selection. With the help of this problem solving constructs the main difficulties, which engineers meet while solving problems, can be analyzed in detail. The constructs as well as the items with their corresponding questions in brackets are illustrated in Table 1 (Hall, 1962; Haberfellner et al., 2012; Ehrlenspiel and Meerkamm, 2013):

Table 1. Constructs and items of problem solving

Constructs	*Items*
Task clarification	situation analysis (1.1.1) and goal formulation (1.1.2)
Solution search	systems synthesis (1.2.1) and systems analysis (1.2.2)
Solution selection	evaluation (1.3.1) and selection (1.3.2)

- *Task clarification* as the first step of problem solving focuses on the analysis of the initial situation in order to formulate goals. The situation analysis considers if the initial situation of the problem setting is analyzed sufficiently. Subsequently, the formulation of goals evaluates to what extent the goals are formulated in terms of requirements.
- *Solution search* as the second step of problem solving comprises the creative synthesis of solutions as well as the crucial analysis of solutions. During the systems synthesis various

variants of solutions are generated based on the situation analysis and goal formation. The systems analysis, however, examines the feasibility of the developed solution concepts.

- *Solution selection* as the third step of problem solving takes the evaluation of the feasible solutions and the selection of the final solution into consideration. The evaluation of solutions compares the different developed solutions based on the requirements generated solution variants. Finally, the optimal solution is selected based on the degree of fulfillment concerning the requirements.

The second dimension of the questionnaire investigates *complexity* of product development from the viewpoint of an engineer. Taking the differentiation between complexity and complicatedness into account, then the subjective evaluation of complexity in a questionnaire represents complicatedness rather than complexity. However, considering a holistic point of view along with the concept of collective intelligence (Rieckher, 1891), then the evaluation represents rather complexity than complicatedness. According to Lindemann et al. (2009) the main constructs for the evaluation of internal complexity are product, process and organizational complexity. The constructs of complexity with their associated items are presented in Table 2.

Table 2. Constructs and items of complexity

Constructs	*Items*
Product complexity	variety (2.2.1), connectivity (2.2.2) and variance (2.2.3)
Process complexity	multidisciplinary (2.3.1), life-cycle (2.3.2) and iteration (2.3.3)
Organization complexity	labor-division (2.4.1), interaction (2.4.2) and hierarchy (2.4.3)

- *Product complexity* of a technical system depends on the variety, the connectivity as well as on the variance of engineering objects. The variety of a technical system refers to the number and types of engineering objects, whereas the connectivity deals with the number and types of engineering object relations (Ehrlenspiel and Meerkamm, 2013; Lindemann et al., 2009; Patzak, 1982). According to Weber (2005) the variance of engineering objects is the third item describing product complexity (Weber, 2005).
- *Process complexity* of product development depends on multidisciplinarity, the life-cycle time as well as on iterations. Multidisciplinary is connected to the number of fields involved in the development of a technical system. Life-cycle time is described as the time to develop new solutions. Iterations represent number of repetitions to find a solution (Lindemann et al., 2009).
- *Organizational complexity* of social systems depends on the division of labor, the interaction and the levels of hierarchy. The distribution of responsibilities for the development of technical systems measures labor-division. Interaction describes the need for coordination between developers. The level of hierarchy is determined by number of organizational level involved (Baccarini, 1996).

Traceability within the scope of the questionnaire represents a quality factor of designing (Storga, 2004). Various traceability constructs characterize the ability to follow EOs in product development. The constructs for the evaluation of traceability are based on the traceability dimensions proposed by Ramesh and Jarke (2001). These dimensions are described by Winkler et al. (2010) as the core questions about EOs that can be answered by traceability. The constructs include objects, subjects, sources, tools, rationales and time. On the basis of these traceability constructs, the items of the questionnaire are developed. Table 3 illustrates each of the six traceability constructs composed of four items, as well as references to their associated questions. Below, the traceability constructs of the questionnaire with its corresponding items are presented in detail (Ramesh and Jarke, 2001; Storga, 2004; Winkler and Von Pilgrim, 2010; Ouertani et al., 2011):

- *What* objects need to be traced in product development? Describes the objects that are engineering objects as well as their engineering object relations. Engineering objects are all artifacts that arise from product development and that are represented by information fragments, e.g. requirements, functions, and components. Engineering object relations are all connections among engineering objects such as aggregation, composition and definition.

Table 3. Constructs and items of traceability

Constructs	*Items*
Object	requirements (3.1.1), functions (3.1.2), elements (3.1.3) and relations (3.1.4)
Subject	creator (3.2.1), modifier (3.2.2), user (3.2.3) and decider (3.3.4)
Source	finding (3.3.1), formal (3.3.2), informal (3.3.3) and implicit (3.3.4)
Tool	documentation (3.4.1), management (3.4.2), propagation (3.4.3) and impacts (3.4.4)
Rationale	record (3.5.1), history (3.5.2), reasons (3.5.3) and impacts (3.5.4)
Time	timestamp (3.6.1), return (3.6.2), comparison (3.6.3) and evolution (3.6.4)

- *Who* are the subjects that need to be traced in product development? Describes the subjects that are responsible for creating, modifying and using engineering objects. Besides, subjects are responsible for engineering decision making to develop products effectively and efficiently.
- *Where* are engineering objects stored as a source in product development? Describes the sources for locating engineering objects, e.g. implicit, informal and formal sources. Implicit sources refer to people, policies or procedures. Informal sources correspond to requirement specifications, meeting minutes or design documentations. Formal sources relate to assemblies, part lists or drawings. Finally, required engineering object need to be found to fulfill the objective.
- *How* are engineering objects used by respective tools in product development? Describes the tools and their functionalities that are used for handling engineering objects and their engineering object relations, e.g. documentation, management, propagation or impact analysis. Documentation and management focus on the representation of engineering objects, whereas, propagation and impact analysis intend to describe the change process of engineering objects by the use of the engineering objects relations.
- *Why* are engineering objects manipulated in product development? Describes the rationale behind creating, modifying and using engineering objects. Especially, the possibility to formally record decisions, thus, to document the history, ensures tracking the reasons and helps estimating the impacts of decisions.
- *When* are engineering objects handled in product development? Describes the time of creating, modifying and using engineering objects. Timestamps of engineering objects and their engineering object relations are necessary to demonstrate the evolution of the product development. Further, versioning is required to return to past design states as well as to compare current solutions with older ones.

4 ANALYSIS AND RESULTS

Although the universal questionnaire itself already represents a novel approach on how to evaluate the need for traceability support in product development, it needed to be conducted in order to prove the above stated hypotheses. The questionnaire as attached was conducted in an early development phase of an automotive original equipment manufacturer. In total, 19 engineers were interviewed in a semi-structured manner. The interviewees were carefully chosen in order to form a representative sample. Due to the hypotheses concerning seniority, young engineers with less responsibility as well as more experienced engineers who gained valuable knowledge during their career were involved. Moreover, to prove the correlation between responsibility and traceability, both, part designers as product managers were consulted. The sample consists of engineers in the age between 25 and over 54 with a seniority of up to 39 years. All interviewees owned at least a master's degree in engineering science, where the majority of the sample had a mechanical engineering background with a focus on technical product management.

The following part describes the *results* of the study. Table 4 shows the correlation matrix of the main constructs of (1) problem solving, (2) complexity as well as (3) traceability. The analysis focuses on the mean value and the standard deviation. Additionally, Pearson's correlation coefficient among the constructs is presented based on the 5-point Likert scale. Internal consistencies of the constructs measured by Cronbach's alpha are presented in brackets.

Table 4. Correlations of the constructs

	Construct	Mean	SD	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	3.4	3.5	3.6
1.1	Task clarification	3.37	0.74	(.61)											
1.2	Solution search	3.79	0.77	.55	(.65)										
1.3	Solution selection	3.61	0.68	.50	.50	(.64)									
2.1	Product complexity	4.35	0.91	.49	.42	.27	(.92)								
2.2	Process complexity	4.03	0.79	.12	.18	−.15	.71	(.48)							
2.3	Organizational complexity	4.05	0.96	.34	.59	.54	.76	.38	(.81)						
3.1	Object traceability	2.95	1.19	.05	−.19	−.22	.19	−.28	−.32	(.86)					
3.2	Subject traceability	3.20	0.91	.13	.04	.14	−.31	.30	.06	.60	(.62)				
3.3	Source traceability	3.37	0.77	.60	.60	.34	.65	.36	.49	.03	.27	(.69)			
3.4	Tool traceability	3.09	0.65	.36	.22	.10	−.42	−.28	−.35	.43	.22	.52	(.70)		
3.5	Rationale traceability	2.63	1.00	−.51	−.32	−.32	−.50	−.37	−.47	.47	.14	−.18	.12	(.83)	
3.6	Time traceability	3.76	0.78	.57	.49	.56	.47	.36	.49	.00	.25	.68	.44	−.36	(.87)

First, regarding *problem solving* it can be stated that the surveyed engineers see the main problem in task clarification. While none of the interviewees answered that they "strongly agree" with the statement that the problem is well defined at the beginning of the product development, they do confirm that enough concepts are developed. However, only half of the sample tends to agree that the solutions are well selected. As a result from the sample, it can be stated that during the product development the phase of task clarification (3.37) and solution selection (3.61) needs to be focused, whereas the "solution variants are developed to a sufficient extend" and "solutions concepts are analyzed sufficiently on feasibility" during the solution search (3.79).

Second, the analysis of *complexity* constructs shows that the highest perceived complexity refers to the product (4.35). Additionally, surveyed engineers on average at least agreed that the complexity of the process (4.03) and the organization (4.05) play an important role during their daily work. Apart from only perceiving the organizational complexity as rather high, the sample as well sees the potential in "supporting of collaboration in product development" (4.21). Moreover, a still great potential lies in improving the handling of process complexity (3.89) and investigating new methods for handling product complexity (3.63). Taken that the internal consistency of the product complexity construct is the highest of all (.92), the construct can be considered as rather reliable.Thus it can be stated that the given construct can be transferred to other contexts as well. In general, it can be stated that the highest potential for future improvements lies in handling organizational complexity (4.21).

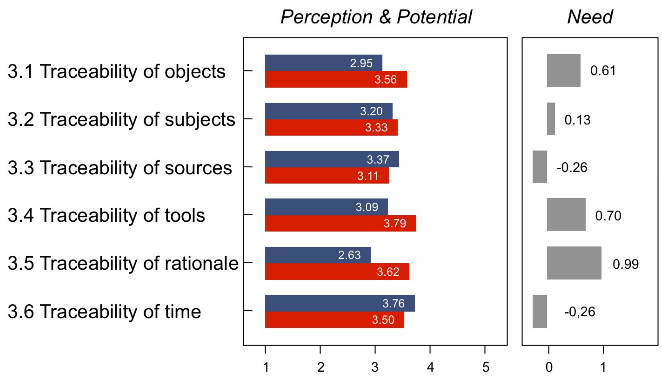

Figure 2. Need for further traceability

Third, the results concerning the need for further *traceability* are visualized in Figure 2. The figure presents the mean values of the perceived traceability (blue) and the potential that the engineers see in the respective constructs (red). Additionally, the need for further traceability support is calculated as difference of the potential and the perceived traceability (grey). Figure 2 shows that tracing objects (2.95) as well as the design rationale (2.63) are the main issues in product development. On the contrary, the majority of interviewees confirmed that their systems landscape enables them to trace time (3.76) and sources (3.37). From the point of the view of the seen potential, the sample is most positive about "providing a tool for tracing engineering objects" (3.79). Finally, the sample clearly identifies the constructs with the biggest need for further traceability support in product development: traceability of rationale (.99), traceability of tools (.70) and traceability of objects (.61).

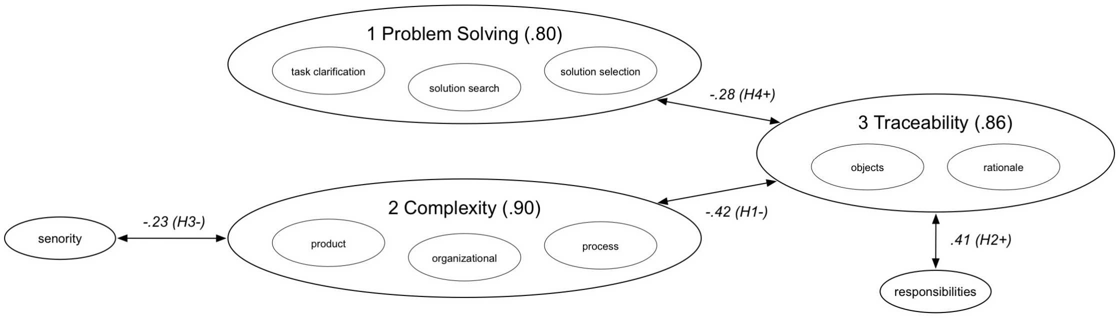

Figure 3. Proof of hypotheses

The following part deals with proving the hypotheses within the framework of the questionnaire. Figure 3 presents only the correlations among those dimensions where the hypotheses were involved. The goal of the research was to understand the correlations of the dimensions in-depth in order to define the context of traceability. First, the results of the study confirm a negative correlation (-.42) between complexity and traceability (H1-). This means that a higher perceived complexity results in a lower perceived traceability of an individual. However, this finding is only valid for the traceability constructs of objects and rationale. Second, the results show a positive correlation (.41) between responsibility and traceability (H2+). That means that the interviewees with higher responsibilities, such as in product management perceive, perceive traceability possibilities as higher. Third, seniority has a slightly negative correlation (-.23) with traceability (H3-). This proves that engineers with a higher seniority perceive less complexity due to their experience. Fourth, problem solving has a negative correlation (-.28) with traceability (H4+). Thus the study disproved this hypothesis, i.e. a better-perceived problem solving leads to less traceability of objects and rationale.

5 CONCLUSION

The *aim* of our paper was to develop a universal questionnaire to evaluate the need for traceability support in the early phase of product development. Therefore, the framework of the questionnaire was presented. The framework illustrated additional dimensions as drivers of traceability, i.e. problem solving, complexity and demographic information. On this basis, the hypotheses regarding the correlations of traceability were stated. Subsequently, the development of the constructs and their items for measuring problem solving, complexity and traceability were introduced. Based on the developed questionnaire a study was conducted. This study demonstrates how to evaluate the need of traceability. Additionally, the study gives insights for further need for traceability: especially traceability of rationale and objects as well as the need for traceability tools. The main contribution of the paper is to provide a universal questionnaire for measuring the ability of problem solving, complexity and the need for traceability in any product development.

The main *limitation* of the paper is the universal – not industry specific – design of the questionnaire. Since the questionnaire design is based mainly on theoretical approaches of problem solving, complexity and traceability, the constructs of these dimensions are quite abstract. However, the questionnaire aims at transferring this abstract construct level to a specific and applicable item level. Apart from that, the paper has limited evidence of reliability of certain constructs and its validity is not proven yet. Further, the study proves the hypotheses of the universal questionnaire; however, the results are quantitatively not significant with nineteen interviewees. Although, the paper focuses on internal observation of only one specific industry, the added value of a universal questionnaire is in providing the possibility to compare results even from different product developments.

The above discussed limitations lead to several *future research* opportunities. First, the questionnaire needs to be conducted in another product development in order to evaluate and compare the need for traceability support. Second, this study will give an important insight about important areas of traceability research in general. Third, applying the questionnaire to other areas would help to analyze the problems concerning traceability as well as give insights about problem solving abilities and perceived complexity. All in all, this paper presented a solid contribution to explore the need of engineers for traceability in any product development in any industry.

REFERENCES

Baccarini, D. (1996) The concept of project complexity. In: International Journal of Project Management, Vol. 14, No. 4, pp. 201–204.

Brandt, S. C., Morbach, J., Miatidis, M., Theißen, M., Jarke, M. and Marquardt, W. (2007) An ontology-based approach to knowledge management in design processes. In: Journal of Computers and Chemical Engineering, Vol. 32, No. 1, pp. 320-342.

Buur, J. and Andreasen, M. M. (1989) Design models in mechatronic product development. In: Design Studies, Vol. 10, No. 3, pp. 155-162.

Ehrlenspiel, K. and Meerkamm, H. (2013) Integrierte Produktentwicklung. Munich: Carl Hanser.

Gideon, L. (2012) Handbook of survey methodology for the social science. New York: Springer.

Gotel, O. C. Z. and Finkelstein, A. C. W. (1994) An analysis of the requirements traceability problem. In: International Conference on Requirement Engineering, pp. 94-102, Colorado Springs.

Haberfellner, R., de Weck, O., Fricke, E. and Vössner, S. (2012) Systems engineering. Zurich: orell füssli.

Hall, A. D. (1962) A methodology for systems engineering. Princeton: Princeton University Press.

IEEE Std. 610.12 (1990) Standard glossary of software engineering terminology. In: IEEE Standards.

Koehler, N., Naumann, T. and Vajna, S. (2014) Supporting the modeling of traceability information. In: International Design Conference, Dubrovnik.

Königs, S. F., Beier, G., Figge, A. and Stark, R. (2012) Traceability in systems engineering. In: Advanced Engineering Informatics, Vol. 26 No. 4, pp. 924-940.

Lindemann, U., Mauerer, M. and Braun, T. (2009) Structural complexity management. Berlin: Springer.

Naumann, T., Königs, S., Kallenborn, O. and Tuttass I. (2011) Social systems engineering - an approach for efficient systems development., In: International Conference on Engineering Design, Copenhagen.

Oppenheim, A. N. (1992) Questionnaire design, interviewing and attitude measurement. London: Pinter Publishers Limited..

Ouertani, M. Z., Baina, S., Gzara, L. and Morel, G. (2011) Traceability and management of dispersed product knowledge during design and manufacturing. In: Computer-Aided Design, Vol. 43, No. 5, pp. 546-562

Patzak, G. (1982) Systemtechnik - Planung komplexer innovativer Systeme", Berlin: Springer.

Ramesh, B. and Jarke, M. (2001) Toward reference models for requirements traceability. IEEE Transactions on Software Engineering, Vol. 27, No. 1, pp. 58-93.

Rieckher, J. (1891) Die Metaphysik des Aristoteles. Stuttgart: Heimann, Stuttgart.

Stark, R. and Figge, A. (2011) Eco tracing - a systems engineering method for efficient tracelink modeling. In: International Conference on Engineering Design, Copenhagen.

Storga, M. (2004) Traceability in product development. In: International Design Conference, Dubrovnik.

Ulrich, K. T. and Eppinger, S. D. (2011) Product development. New York: McGraw.

Vajna, S., Weber, C., Bley, H., Zeman, K. and Hehenberger, P. (2009) CAx für Ingenieure: eine praxisbezogene Einführung. Berlin: Springer.

Weber, C. (2005) What is complexity? In: International Conference on Engineering Design, Melbourne.

Winkler, S. and Von Pilgrim, J. (2010) A survey of traceability in requirements engineering and model-driven development. In: Software and Systems Modeling, Vol. 9, No. 4, pp. 529–565.

APPENDIX

Nico Koehler | Digital Product Modelling
Traceability in Integrated Product Development

Thank you for participating in this study about complexity and traceability during the problem solving in the early product development. The goal of the study is to align the development of future methods and tools according to your needs. The study contains three main parts on four pages and takes about 10 to 20 minutes. Please read every question in detail and mark the answer that fits your opinion best. Please answer each question efficiently and carefully, to the best of your ability. Even if a decision is difficult, mark the answer that fits your opinion best.

Answer:	☒	Mark the answer that fits best
Correction:	■	Indicate any correction clearly

Due to the protection of data privacy we point out that all information you give is voluntary. Your information is handled anonymously and will not be disclosed. Therefore, there is no possibility to trace your personal answers.

1 Problem-Solving in Product Development

The following part of the study deals with problem solving in product development. Problem solving in terms of this study describes the cognitive activities for solving a problem based on *available information*. Please evaluate each of the following statements between "strongly disagree" (1) and "strongly agree" (5).

1.1 During the task clarification in my work environment …	1	2	3	4	5
… the initial situation of the problem is analyzed sufficiently.	☐	☐	☐	☐	☐
… the goal is formulated sufficiently in terms of requirements.	☐	☐	☐	☐	☐

1.2 During the search for solutions in my work environment …	1	2	3	4	5
… solutions variants are developed to a sufficient extent.	☐	☐	☐	☐	☐
… solutions concepts are analyzed sufficiently on feasibility.	☐	☐	☐	☐	☐

1.3 During the solution selection in my work environment …	1	2	3	4	5
… all variants are evaluated sufficiently based on their requirements.	☐	☐	☐	☐	☐
… the optimum solution is selected due to its performance.	☐	☐	☐	☐	☐

1.4 Do you have any comments on the this part of the study?

2 Complexity in Product Development

The following part of the study deals with the complexity of the development of technical systems. Complexity in terms of this study describes the level of difficulty of the product development. In the following, engineering objects represent information specifying the product, e.g. requirements, functions or components. Please evaluate each of the following statements between "strongly disagree" (1) and "strongly agree" (5).

Nico Koehler | Digital Product Modelling
Traceability in Integrated Product Development

2.1 The complexity of the product development …	1	2	3	4	5
… in my daily work environment is high.	☐	☐	☐	☐	☐
… has increased significantly in recent years.	☐	☐	☐	☐	☐
… is high in today's dynamic work environment.	☐	☐	☐	☐	☐
… is difficult to handle with today's methods.	☐	☐	☐	☐	☐

2.2 During my daily work …	1	2	3	4	5
… the variety of handled engineering objects is high.	☐	☐	☐	☐	☐
… the connectivity among the engineering objects is high.	☐	☐	☐	☐	☐
… the variance of the product's engineering objects is high.	☐	☐	☐	☐	☐

2.3 During my daily work …	1	2	3	4	5
… the number of involved development disciplines is high.	☐	☐	☐	☐	☐
… the development cycles for new solutions are short.	☐	☐	☐	☐	☐
… the number of iterations for the solution search is high.	☐	☐	☐	☐	☐

2.4 During my daily work …	1	2	3	4	5
… the labour-division for system's development is high.	☐	☐	☐	☐	☐
… the need for coordination between developers is high.	☐	☐	☐	☐	☐
… the number of organizational hierarchy level is high.	☐	☐	☐	☐	☐

2.5 I see great potential …	1	2	3	4	5
… in investigating new product development methods.	☐	☐	☐	☐	☐
… in improving of product development processes.	☐	☐	☐	☐	☐
… in supporting of collaboration in product development.	☐	☐	☐	☐	☐

2.6 Do you have any comments on the this part of the study?

3 Traceability in Product Development

The following part of the study deals with traceability of engineering objects necessary for the development of technical systems. Traceability in terms of this study describes the ability to follow every engineering object from its origin to its final use in the product. Please evaluate each of the following statements between "strongly disagree" (1) and "strongly agree" (5).

3.1 The existing system landscape enables me … …	1	2	3	4	5
… to handle requirements as an engineering object.	☐	☐	☐	☐	☐
… to handle functions as an engineering object.	☐	☐	☐	☐	☐
… to handle elements as an engineering object.	☐	☐	☐	☐	☐
… to handle relations among engineering objects.	☐	☐	☐	☐	☐

3.2 The existing system landscape enables me … …

	1	2	3	4	5
… to identify the creator of an engineering object.	☐	☐	☐	☐	☐
… to identify the modifier of an engineering object.	☐	☐	☐	☐	☐
… to identify the user of an engineering object.	☐	☐	☐	☐	☐
… to identify the decider of an engineering object.	☐	☐	☐	☐	☐

3.3 The existing system landscape enables me … …

	1	2	3	4	5
… to identify required engineering objects through PDM.	☐	☐	☐	☐	☐
… to identify relations among engineering objects through CAD.	☐	☐	☐	☐	☐
… to identify relations among engineering objects through documents.	☐	☐	☐	☐	☐
… to identify relations among engineering objects through colleagues.	☐	☐	☐	☐	☐

3.4 The existing system landscape enables me … …

	1	2	3	4	5
… to document relations among engineering objects.	☐	☐	☐	☐	☐
… to manage relations among engineering objects.	☐	☐	☐	☐	☐
… to propagate changes of engineering objects.	☐	☐	☐	☐	☐
… to estimate impacts of engineering changes.	☐	☐	☐	☐	☐

3.5 The existing system landscape enables me … …

	1	2	3	4	5
… to record design decisions related to engineering objects.	☐	☐	☐	☐	☐
… to retrieve design decisions of engineering objects.	☐	☐	☐	☐	☐
… to understand reasons for changes of engineering objects.	☐	☐	☐	☐	☐
… to estimate impacts of design decisions of engineering objects.	☐	☐	☐	☐	☐

3.6 The existing system landscape enables me … …

	1	2	3	4	5
… to identify the access time of an engineering object.	☐	☐	☐	☐	☐
… to return to previous versions of an engineering object.	☐	☐	☐	☐	☐
… to compare different engineering object temporally.	☐	☐	☐	☐	☐
… to view the history of an engineering object.	☐	☐	☐	☐	☐

3.7 I see great potential …

	1	2	3	4	5
… in tracing all engineering objects by use of their relations.	☐	☐	☐	☐	☐
… in recording all subjects handling engineering objects.	☐	☐	☐	☐	☐
… in identifying the sources of engineering objects.	☐	☐	☐	☐	☐
… in providing a tool for tracing engineering objects.	☐	☐	☐	☐	☐
… in recording design decisions of engineering objects.	☐	☐	☐	☐	☐
… in accessing an engineering object at any point in time.	☐	☐	☐	☐	☐

3.8 Do you have any comments on the this part of the study?

4 Demographical Information

Finally, we need some demographical information from you for the analysis of the study. Please answer the following questions.

4.1 How old are you?

- ☐ under 25 years
- ☐ between 25 and 34 years
- ☐ between 35 and 44 years
- ☐ between 45 and 54 years
- ☐ over 54 years

4.2 What is your seniority?

- ☐ less than 10 years
- ☐ between 10 and 19 years
- ☐ between 20 and 29 years
- ☐ between 30 and 39 years
- ☐ more than 39 years

4.3 What is your highest degree?

- ☐ High School
- ☐ Bachelor's Degree
- ☐ Master's Degree
- ☐ Doctor of Philosophy

4.4 What is you specialization?

- ☐ Computer science
- ☐ Electrical engineering
- ☐ Mechanical engineering
- ☐ Economic science

Others:

4.5 What are your responsibilities

- ☐ Component development
- ☐ Systems development
- ☐ Product management
- ☐ Project management
- ☐ Process management
- ☐ Requirements management

Others:

4.6 Gender?

- ☐ male
- ☐ female