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SYSTEMATIZATION OF EXISTING UNCERTAINTIES IN THE CONTEXT OF PRODUCT DEVELOPMENT IN THE AUTOMOTIVE SUPPLY INDUSTRY

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ABSTRACT

Along the development process of technical products, challenges arise repeatedly, which result from uncertainties, i.e., conscious, or unconscious gaps in knowledge or definitions. The causes often lie in the fact that empirical values represent the basis for many decisions, from the specification of tasks to the required organizational and control structures to the models and calculation tools used. Based on this knowledge, it is essential to continuously identify, evaluate and, if necessary, reduce the degree of uncertainty during the development of innovative products. This is intended to avoid potentially negative influences on the strategic goals of the magic triangle of project management (costs, time, and quality). This is exactly where the investigations started, using the example of an automotive supplier company. Completed projects are the starting point. A first focus is on the analysis of the effects of unclearly defined requirements and ambiguities in verification, validation, and end customer use. A second focus is the systematization, classification up to the provision of project-specific tools, which should facilitate the reduction of uncertainties already in early project phases.

1. INTRODUCTION AND OBJECTIVES

Across the development process of technical products, challenges arise again and again that result from uncertainties, i.e., conscious, or unconscious knowledge or definition gaps [1]. The causes often lie in the fact that empirical values form the basis for many decisions, from the specification of the task to the required organizational and management structures, to the methods, models and computational tools used. Uncertainties are an inherent part of every project, and even careful planning cannot cover all eventualities. Based on this realization, it is essential to continuously identify, evaluate, and where possible reduce the level of uncertainty during the development of innovative products [2]. This is to avoid potentially negative influences on the strategic goals of the magic triangle of project management (cost, time and quality) [3]. This is exactly the starting point for the investigations using the example of an automotive supplier. Retrospectively, conclusions for future fields of action and optimizations in the applied methodology are to be pointed out based on the findings from completed projects. To achieve this goal and to be able to derive concrete measures, a comprehensive understanding of the existing uncertainties and their causes is first required. To this end, interviews are conducted with company employees who can provide information about the uncertainties and their causes. For detailing and clustering, the results are placed in the context of existing models. A more detailed description of the interview procedure is given in chapter 3.

2. STATE OF THE ART

Several definitions for the concept of uncertainty in the product development environment can be found in the literature. McManus and Hastings define the term uncertainty as knowledge or definition gaps. The term knowledge gap was defined by an insufficient level of knowledge about the technical product to be developed at the time of the decision. Definition gaps exist when knowledge or information for decisions, requirements or specifications are not defined at all, or not defined in sufficient detail. [4] To categorize and structure the identified uncertainties, established models were used in the context of this paper. The ASPICE [5] and project management [6] structuring options served as initial approaches to structuring the uncertainties. The problem characteristics according to VDI 2221 [7] and the classification of uncertainties according to Kesselring [8], who distinguishes between technical, economic and aesthetic uncertainties, serve as further categorization possibilities and aids. There are already numerous methods and approaches for reducing uncertainties and increasing the maturity of product development, which were identified in advance through a literature review. According to de Neufville et. al [9] the core of the necessary knowledge gain in technical development is the verification and validation of the previously defined requirements. According to the principles of product development, any development process aims to increase the maturity of a product and, conversely, to reduce the degree of uncertainty by increasing knowledge [10]. The V-model, which is derived from systems engineering, presents itself as a control loop with its structured procedure from the elicitation and analysis of requirements to the validation of the developed system by the end user. In this way, findings from verification can be incorporated back into the requirements and the design. [11]

3. METHODS AND PROCEDURE

The starting point for achieving the goal is a comprehensive survey of the status quo. This survey is based on interviews with experienced developers from various specialist departments. Concrete problems from completed projects of an automotive supplier are used as examples. During the interviews, care was taken to ensure that the experts interviewed covered as broad a spectrum of expertise as possible, such as project engineers, project managers, test engineers and component developers. Other criteria for selecting the interviewees were their responsibility for achieving the technical and economic project goals, and the distinction between predevelopment and series development. Care was also taken to ensure that all interviewees had more than 5 years of professional experience. This was to serve as further evidence of their respective expertise. Table 1 shows the concrete composition of the interviewees according to their position in the company and their respective professional experience in years.

Table 1: Interviewees composition

Position	**Work experience in years**
Director Systems Engineering und Application	14
Engineer concept development	24
Manager concept development	20
Manager strategy and Business development	15
Manager advanced development	20
Manager advanced development	14
Project manager series development	7
Project manager series development	14
Project manager advanced delopment	9
Team leader	20
Team leader standard components	19
Team leader simulation	13
Team leader validation	12
Team leader validation	15
Team leader advanced development	20
Sum:	**236**

As a tool and to classify the objective, the interviewees were provided in advance of the interviews with the classification of uncertainties according to Kesselring [8]. To empirically capture representative uncertainties from completed product development projects and their respective causes, as well as to ensure a uniform structure across all interviews, seven predefined questions were answered in a one-hour interview. Figure 1 lists the questions asked.

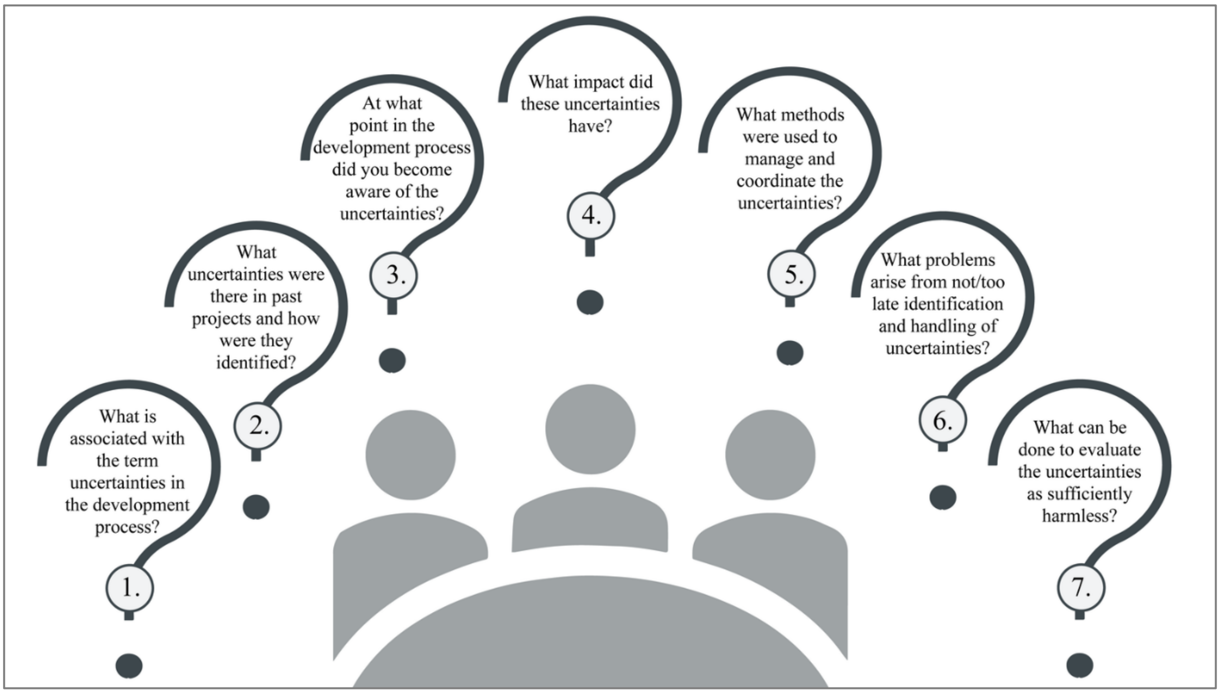

Figure 1: Interview questions

The questionnaire is structured in such a way that first the general associations of the interview participants on the topic of uncertainties are queried. Then the interviewees select uncertainties from their previous projects to examine them in more detail. This leads to a thematization of the emergence, identification, and impact of uncertainties on project success, but also of the methods and measures used to deal with uncertainties. At the end of the interviews, respondents are asked for suggestions for improvement. In the event of contradictions in the information, e.g., if experts have worked on the same development project, queries are unavoidable for a more precise evaluation of the interview responses. After collecting the interview data, it is necessary to examine and summarize the uncertainties in more detail.

Therefore, for a more detailed analysis of the uncertainties, the methods described in Sect. 2 are used as classification schemes.

A total of 37 uncertainties were identified, forming the data basis for several classification schemes. This multi-stage classification step (Sections.4.1 4.4to 4.7) includes the following seven categorizations:

- ASPICE grouping (*Automotive Software Process Improvement and Capability Determination*, see ISO/IEC XX) according to [5]
- Project management risk classification (www.pm-knowhow.ch) according to [6]
- Phase-specific assignment based on the V-model according to [11]
- Characteristics of complex problems according to VDI 2221 [7]
- Epistemic and aleatory uncertainties according to. [12]
- Knowledge and definition gaps according to [4]
- Technical, economic and aesthetic uncertainties according to. [8]

Special importance is attached to the V-Modell as a process model to find out in which phase of the V-Modell the uncertainties occurred, e.g., whether the uncertainties were already present in the customer specifications or whether the uncertainties only occurred during the product design. In addition to the occurrence of the uncertainties, the actual identification of the uncertainties by the respective project team is also analyzed with the help of the V-Modell. The characteristics of complex problems described in the VDI 2221, [7] whose classification is based on the dimensions of lack of transparency, polytely, interconnectedness and (intrinsic) dynamics, are also applied to the uncertainties under consideration. In addition, a differentiation is made between epistemic and aleatory uncertainties [12] as well as a classification into technical, economic and aesthetic uncertainties according to Kesselring [8].

4. RESULTS

4.1 Results from categorization according to ASPICE

Even though the focus of ASPICE is on system and software development, their groups at the highest level of abstraction are suitable for categorizing the evaluated uncertainties. This makes it possible to ensure that uncertainties are appropriate for the focus of this study at the analysis stage and, if necessary, to exclude groups of ASPICE whose uncertainties are not to be examined in detail in this framework. The focus for further investigation is on the primary life cycle processes and the associated concrete development of technical products. [5]

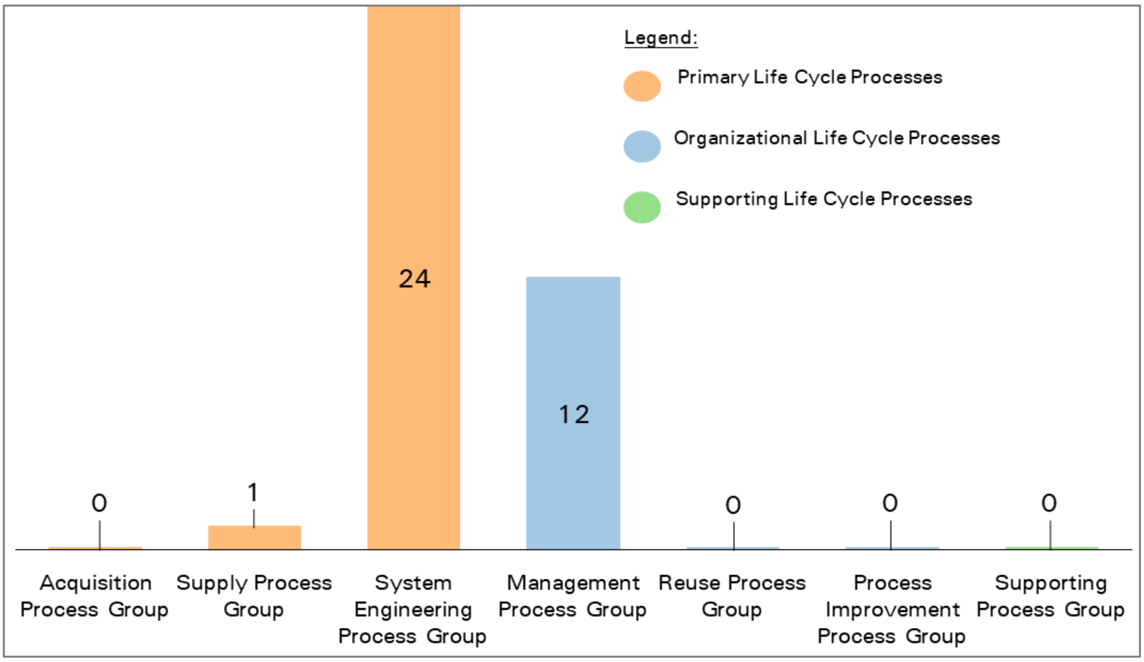

Figure 2: Categorization according to ASPICE based on [5]

As shown in Figure 2, 24 of the 37 uncertainties mentioned can be classified in the group of *System Engineering Process*. One uncertainty could be assigned to the *Supply Process* group. None of the uncertainties could be assigned to the *Acquisition*, *Reuse*, *Process Improvement* and *Supporting Process* groups. 12 mentions can be assigned to the *Management Process Group*. To prevent misinterpretation, it should be noted here that the groups of uncertainties have resulted from the selection of respondents and are intended to ensure that the focus is on technical development.

4.2 Results from categorization according to project management risks

The project management according to [6] distinguishes the following four main risk categories:

- technical risks
- organizational risks
- Project management risks and
- external risks

Examples of technical risks include quality risks, changes in industry standards and general technical feasibility.

Organizational risks focus on available resources and their distribution within the company. Project management risks, on the other hand, relate to the concrete implementation of the respective project using resources, time and financial means. Another example of project management risks is also an unacceptable work result. As external risks Heini defines [6] legal influences, risks due to force majeure or risks that cannot be influenced by the respective organization. [6]

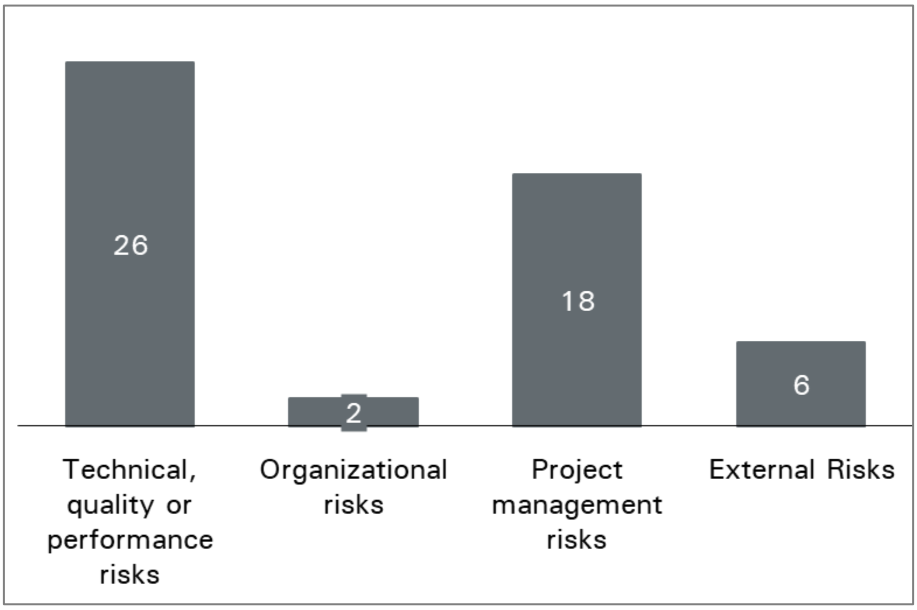

Figure 3: Number of uncertainties mentioned and their categorization according to [6]

In the case of the Figure 3, 26 of the 37 uncertainties mentioned could be assigned to the category of technical, qualitative or performance-related risks. Only 2 of the uncertainties mentioned could be assigned to the category of organizational risks. 18 of the 37 uncertainties were attributable to project management risks and 6 uncertainties to external risks. Each uncertainty could potentially also be assigned to more than one category, and this was evaluated depending on the respective uncertainty. Accordingly, the total of 37 uncertainties mentioned are to be regarded as the basis of the evaluation.

4.3 Results from categorization according to V-Modell

The V-model used in the system development [11] is used to classify the uncertainties mentioned. It highlights when the uncertainties occurred in the development process and when they were recognized or identified by the project team.

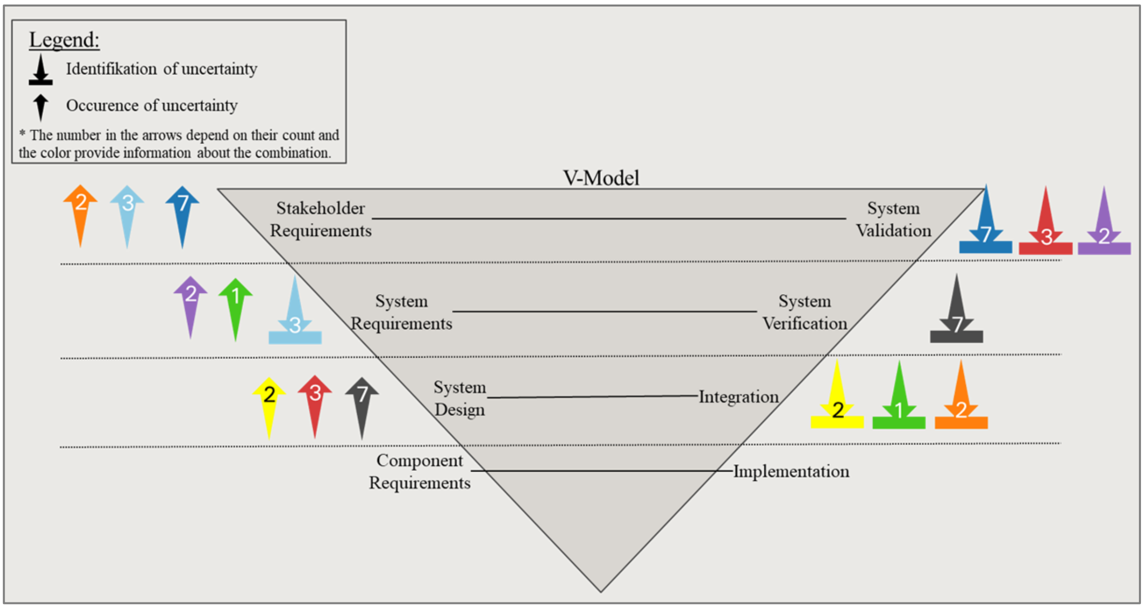

Figure 4: V-model with the phase-specific indication of the occurrence of uncertainties and their identification according to [11]

Figure 4 shows how often the respective pairings of occurrence and identification of the respective uncertainties came up along the V-model. The respective combinations or pairings are assigned to each other by color and symbolically. In addition, the numbers within the arrows indicate how often a respective combination occurred for the uncertainties shown. Each combination is described in the further course of this chapter (Section 4.3.1 to section 4.3.8) in more detail and specific reasons for their occurrence are pointed out. The Figure 5 to Figure 12 serve the better understanding and/or for the better classification into the V-Modell. They build on Figure 4 and illustrate the relationships between the development and identification of uncertainties. It should be noted that not all the uncertainties derived from the interviews could be integrated into the V-Modell, but only 27 of the 37 uncertainties mentioned.

4.3.1 V-Model - From "Stakeholder Requirements" to "System Requirement "

Figure 5 shows the uncertainties that had their occurrence in the "Stakeholder Requirements" phase and were identified in the transition to the "System Requirements" phase. This combination occurred in 3 of the 27 uncertainties.

Three developmental reasons for early identification could be derived from the interviews:

- The first reason was the existing expert knowledge in the project team, which pointed out relevant issues from past projects, allowing them to be considered in the system requirements.
- The second reason is due to an extensive requirements analysis. In the process, inconsistencies within the development specification provided by the customer and in comparison, to a generic development could be identified and adjusted.
- The third reason is due to a management decision to cancel the project for commercial reasons.

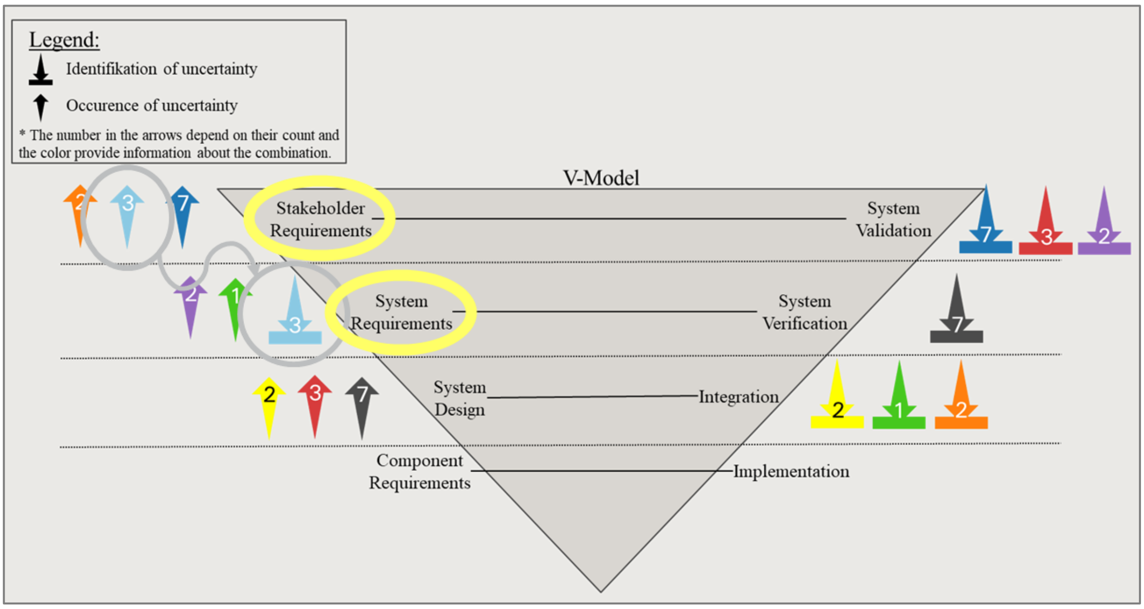

Figure 5: Occurrence in "Stakeholder Requirements" phase and identification in "System Requirements" phase in extension Figure 4

4.3.2 V-Model - From "Stakeholder Requirements" to "System Validation

Figure 6 shows in comparison to Figure Figure 5 shows a completely different case, where the uncertainty was only identified during the "System Validation" of the product, although it already occurred in the "Stakeholder Requirements" phase. Overall, this combination occurred more frequently, with seven mentions.

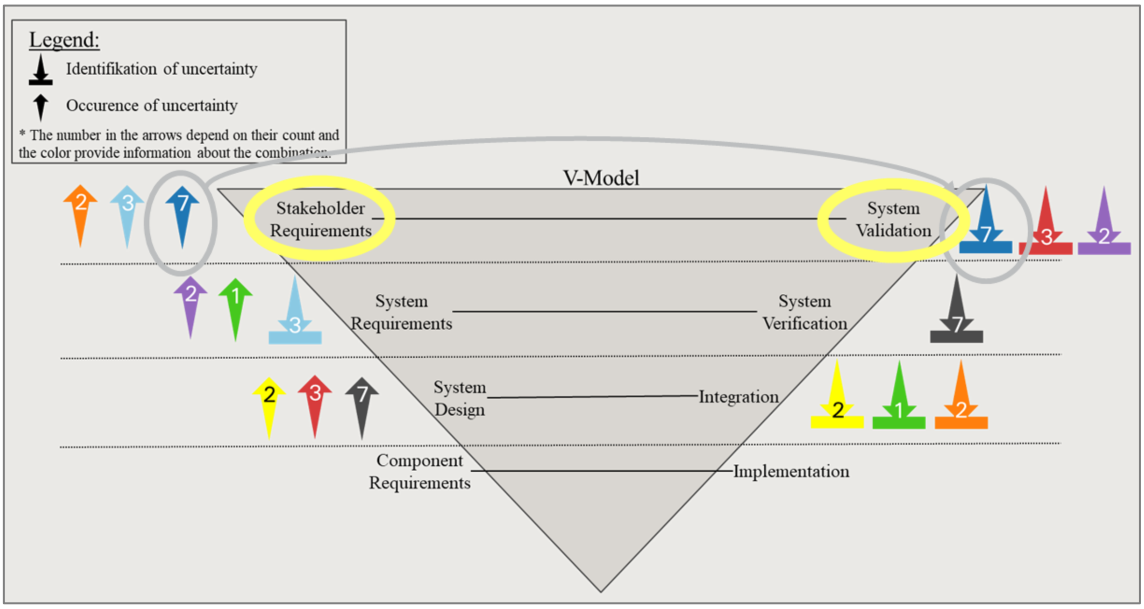

Figure 6: Occurrence in "Stakeholder Requirements" phase and identification in "System Validation" phase in extension to Figure 4

The reasons identified in this combination were defined as follows:

- On an organizational level, project hours were not scheduled for necessary iteration loops within development.
- The clarification of customer acceptance for system functions worked out in advance were also to be classified here.
- In addition, an uncertainty was included in this combination, which could only be identified in the actual application environment, as this was due to environmental requirements, such as dust compatibility.

4.3.3 V-Model - From "System Design" to "System Validation

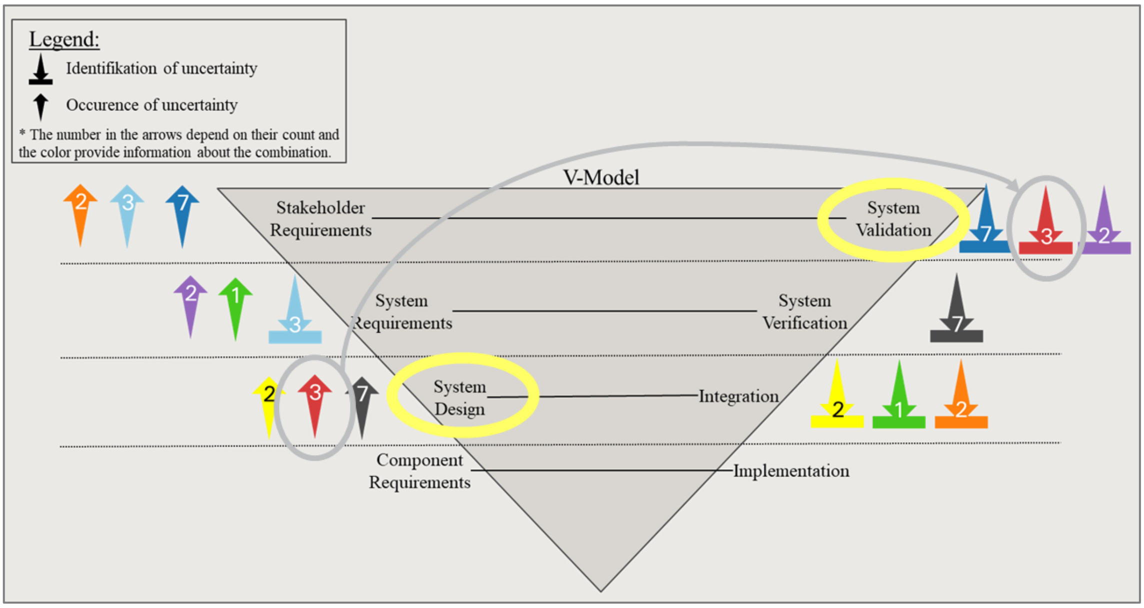

Figure 7: Occurrence in "System Design" phase and identification in "System Validation" phase in extension to Figure 4

Figure 7 visualizes the fact that the uncertainties mentioned had their occurrence in the "System Design" and these were recognized in the "System Validation". Three of the uncertainties were assigned to this combination.

The reason for the combination was the lack of market acceptance of the technical solution presented or the focus on a supposedly preferred solution that was ultimately not accepted by the customer.

4.3.4 V-Model - From "System Design" to "System Verification

Figure 8 shows the case where the uncertainty occurred in the "System Design" and was detected in the "System Verification", i.e., the actual testing of the components. The combination was mentioned seven times. In this combination, the detection of the uncertainty was possible through physical testing, with anomalies occurring in endurance testing, acoustics and electromagnetic compatibility. The reasons for this were any failures and abnormalities in the tests.

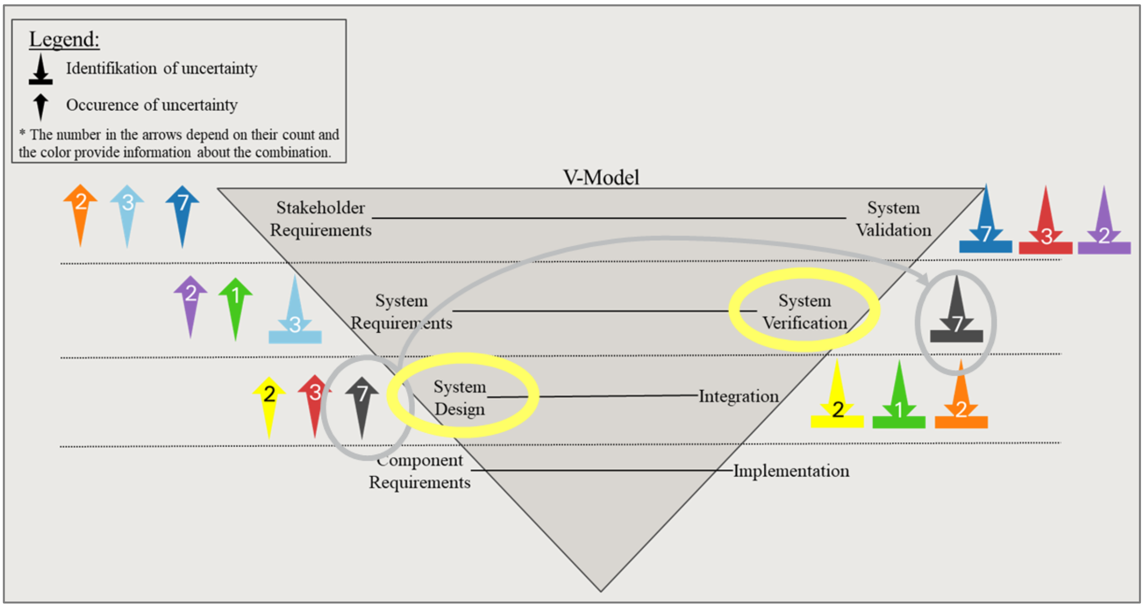

Figure 8: Occurrence in "System Design" phase and identification in "System Verification" phase in extension to Figure 4

4.3.5 V-Model - From "System Design" to "Integration

Figure 9 represents the combination of an occurrence of the uncertainty in the "System Design" interpretation and an identification of the uncertainty in the “Integration" phase. Two of the uncertainties could be classified into this combination.

The uncertainties related on the one hand to the warpage of plastic parts, which made assembly difficult, and on the other hand to the incorrect design of the necessary preload for plastic parts.

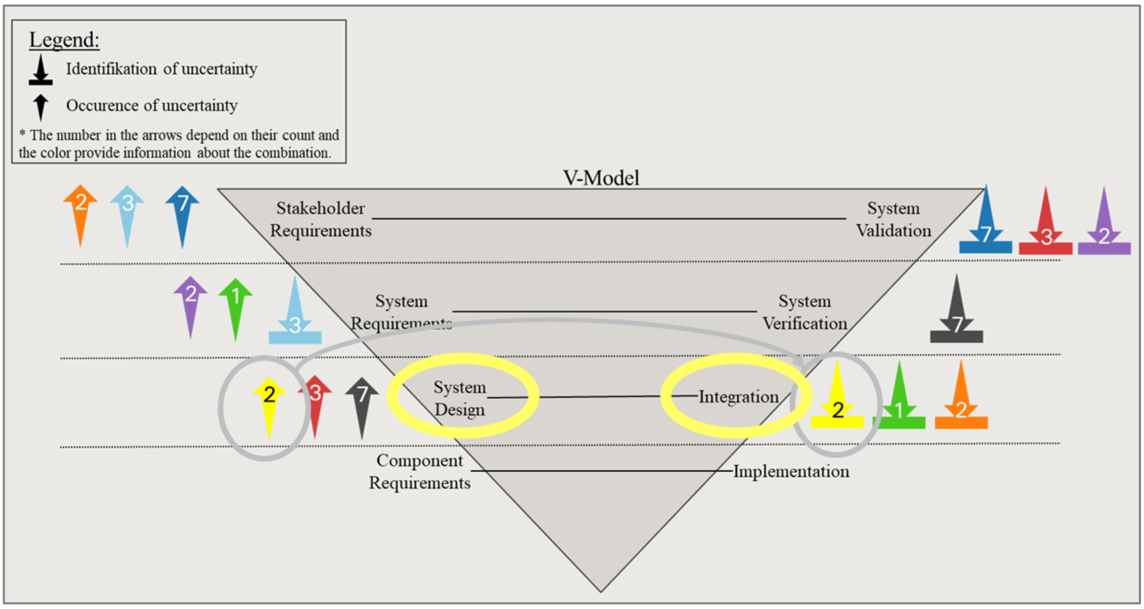

Figure 9: Occurrence in "System Design" phase and identification in "Integration" phase in extension to Figure 4

4.3.6 V-Model - From "System Requirements" to "Integration

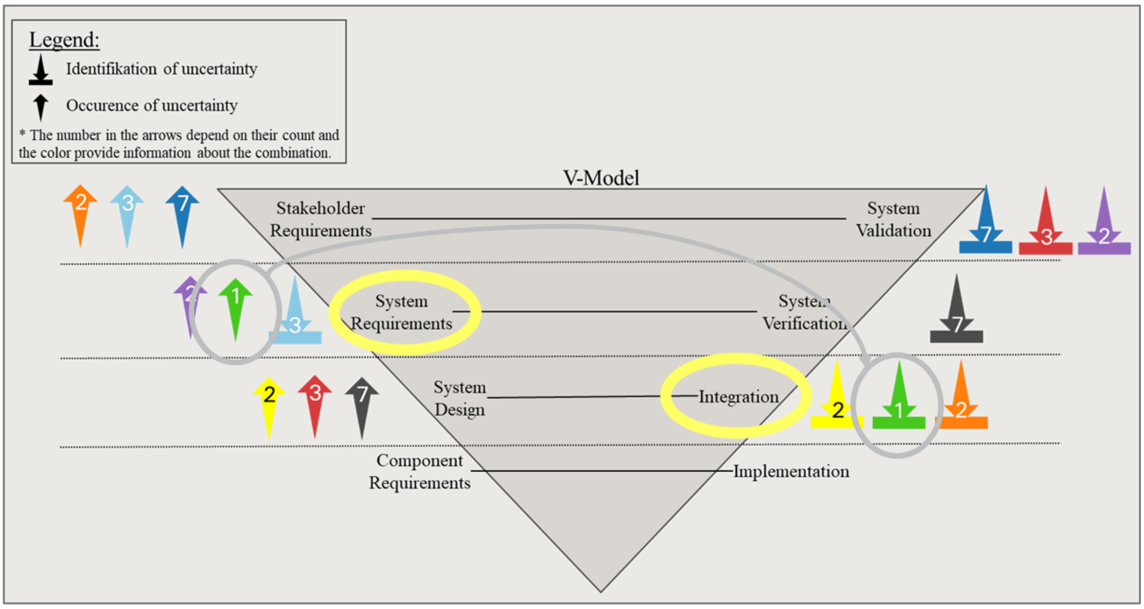

Figure 10: Occurrence in "System Requirements" phase and identification in "Integration" phase in extension to Figure 4

Figure 10 visualizes the fact that the uncertainty occurred in the "System Requirements" and was identified by the project team in the "Integration" phase when building a physical prototype. One of the investigated uncertainties could be classified in this category.

The interviewee cited insufficient basic knowledge of the application under consideration as the reason, which in turn led to inadequate simulation models and thus to insufficient stiffness values being designed in the system.

4.3.7 V-Model – From "Stakeholder Requirements" to "Integration"

Figure 11 shows the case when the uncertainty occurs within the "Stakeholder Requirements" phase but is not identified until the "Integration" phase. Two of the 27 uncertainties could be sorted into this combination.

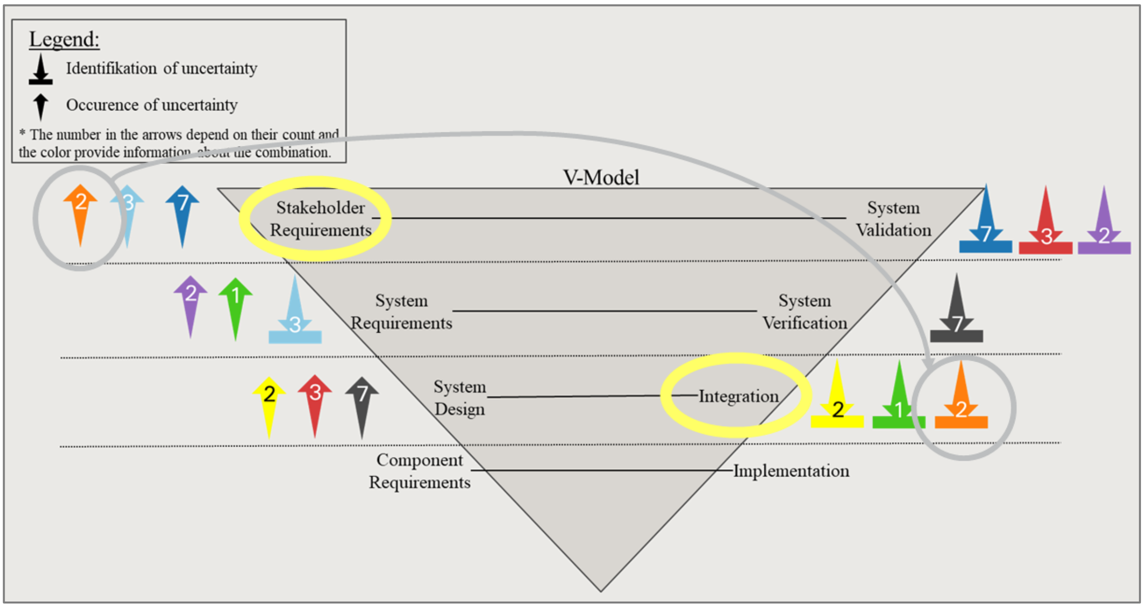

Figure 11: Occurrence in "Stakeholder Requirements" phase and identification in "Integration" phase in extension to Figure 4

In both cases, this combination was since the customer provided insufficient information or even none. In one case, this meant that it was no longer possible to assemble the components because another supplier had changed its interface without passing on this information. In the case of the other uncertainty, an incorrect gap dimension occurred, whereby the company's own products had no direct influence here, but still had to be adjusted afterwards.

4.3.8 V-Model - From "System Requirements" to "System Validation "

Figure 12 shows the combination of an identification in the "System Validation" and an occurrence in the "System Requirements" phase. Two of the considered uncertainties were in this combination.

The reason for this combination can be traced back to vaguely formulated customer requirements, whereby these demanded a customer function, and the customer also did not yet have any concrete ideas about feasibility and implementation. As a result, the customer function had to be substantiated with many assumptions, which became concrete in the validation by customers.

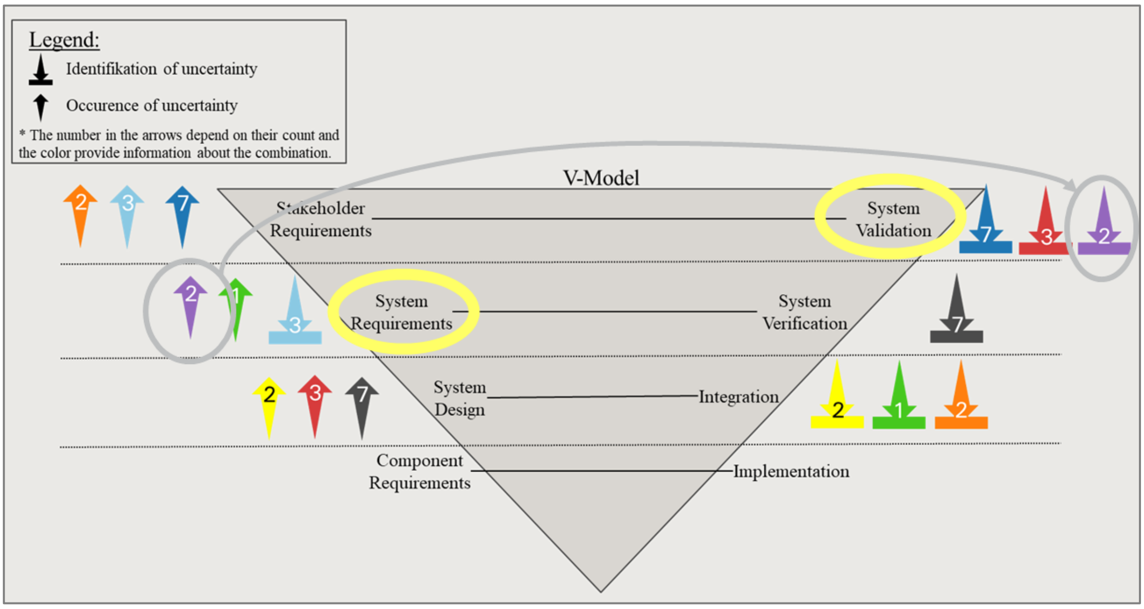

Figure 12: Occurrence in "System Requirements" phase and identification in "System Validation" phase in extension to Figure 4

4.4 Results from categorization according to the problem characteristics of VDI 2221

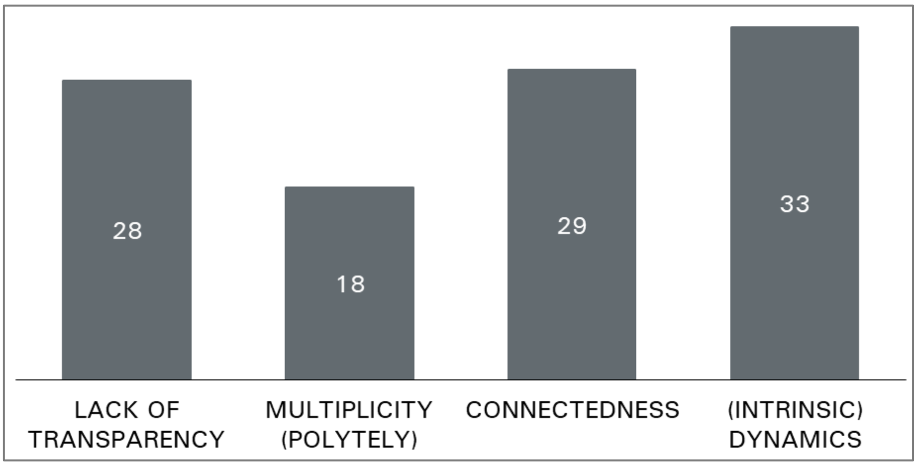

Figure 13: Categorization of problem characteristics according to VDI 2221 based on [7]

VDI 2221 distinguishes the following four characteristics of uncertainties in problem handling in the development process:

1. The lack of transparency refers to the insufficient traceability of decisions and assumptions about the target and actual states along the technical development.
2. Multiplicity or Polytely refers to the presence of multiple project goals that are partially contradictory.
3. Connectedness or interdependence refers to the mutual influence of problem and solution components.
4. Intrinsic dynamics characterizes any problem that changes over the course of a project or changes over time. [7]

When classifying the uncertainties mentioned above (see Figure 13) into the problem characteristics of VDI 2221, intrinsic dynamics was listed most frequently with 33 mentions. The lack of transparency was named as a problem of uncertainty with 28 mentions. Similarly, often, and with 29 mentions, interdependence was the problem. With 18 mentions, polytely was less frequently the problem of the total uncertainties considered.

Each uncertainty could also be placed in more than one category if it was caused by multiple factors.

4.5 Results according to epistemic or aleatory uncertainties

For the definition of epistemic and aleatory uncertainties the definition of M. Havbro Faber was used, who describes aleatory uncertainties as uncertainties due to natural fluctuations and chance. Epistemological uncertainties are defined as uncertainties due to incomplete knowledge that can be reduced or eliminated through knowledge building. [12]

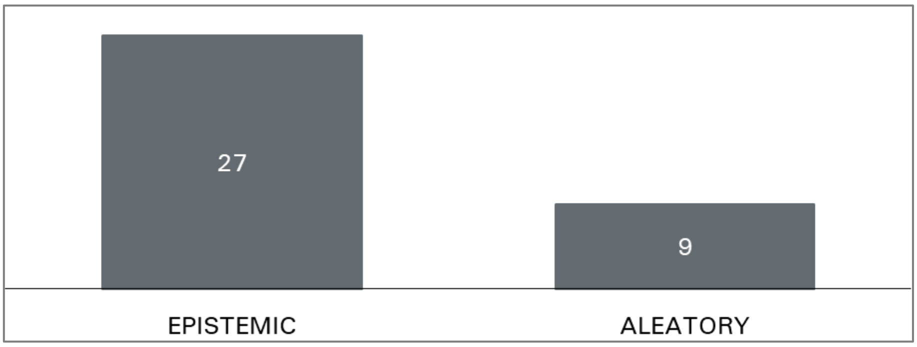

Figure 14: Categorization in epistemic and aleatory uncertainties based on the definition of [12]

In the classification of uncertainties into epistemic and aleatory uncertainties a clear differentiation was possible, but only 36 of the 37 uncertainties mentioned could be classified in this way. Figure 14 shows that 27 uncertainties could be assigned to the epistemic side and 9 aleatory uncertainties were present in the results of the surveys.

4.6 Results according to knowledge and definition gaps

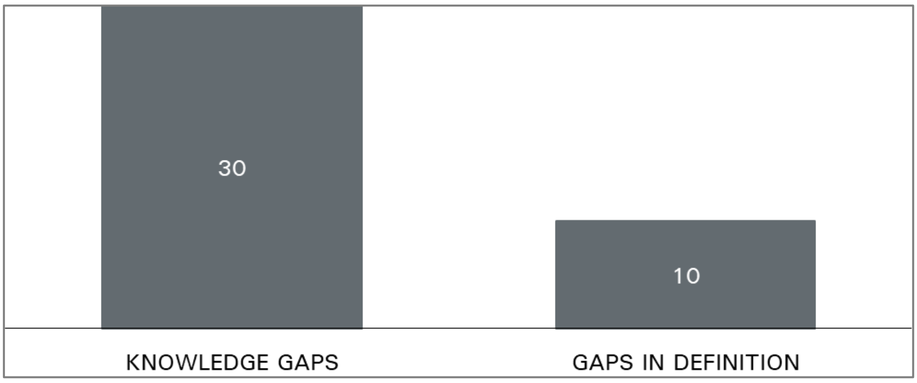

Figure 15: Categorization of knowledge gaps and gaps in definition

In the following section, the identified uncertainties are classified according to the definition of McManus and Hastings, into knowledge and definition gaps. [4] As Figure 15 the majority (30 out of 37) of the uncertainties mentioned were knowledge gaps. For 10 of the uncertainties a definition gap could be assumed.

In some cases, there was no clear assignment to a category according to the definition of [4] whereby three of the uncertainties mentioned were both a knowledge gap and a definition gap. This in turn is since, in addition to the lack of basic knowledge, essential requirements were also not defined.

4.7 Results according to technical, economic or aesthetic uncertainties

According to the classification of uncertainties in the context of technical product development according to Kesselring, there are, as already briefly mentioned at the beginning, three potential dimensions. The technological uncertainties, which according to Kesselring are knowledge and definition gaps regarding the technical feasibility of the products. [8] Furthermore, the economic uncertainties, which according to [13] focuses on the target markets, customer needs, willingness to pay and use cases. Finally, there is the dimension of aesthetic uncertainties, which is associated as the impressions associated by a user with the product and the associated acceptance of the user. [14]

When applying the classification to the topics considered, it was not possible in some cases to clearly assign the uncertainties to a dimension, so that multiple responses are possible. Of the total of 37 uncertainties mentioned, 37 were included in the scheme of Kesselring [8]. Figure 16 shows that 26 uncertainties could be assigned to the technological dimension, 14 to the economic dimension and 9 to the aesthetic dimension.

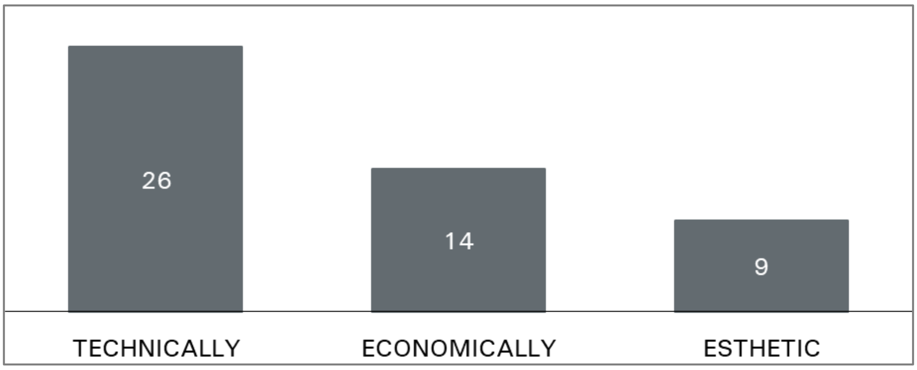

Figure 16: Categorization according to the triangle of Uncertainty based on the Definition of [8]

5. DISCUSSION

In this first elaboration on failure analysis at an automotive supplier, it becomes clear that uncertainties occur along the development process that have not yet been recognized, categorized and evaluated in the company. The hypothesis was that through a fundamental analysis, classification and evaluation of the uncertainties raised, patterns can be identified which serve to uncover concrete fields of action in which optimization opportunities lie for the company under consideration.

The hypothesis was that by classifying and evaluating the collected uncertainties, patterns can be identified that serve to uncover concrete fields of action where optimization opportunities lie for the company under consideration.

When considering according to ASPICE [5] and the project management risks according to [6] showed that there were no discrepancies in the uncertainties mentioned, indicating that the results of the interviews meet the intended focus of the technical development.

Due to the possibility of multiple naming in the problem characteristics of VDI 2221, no clear differentiation was possible. The conclusion that can be drawn from the evaluation is that problem of uncertainty was less frequently polytely. As a result, it can be stated at this point that the classification of the 37 uncertainties mentioned in the problem characteristics of VDI 2221 [7], in the context of this study, was found to be not very purposeful. Reasons for this can also be a lack of theoretical background knowledge or a lack of detailed reflection of completed projects in detail. Further investigations are required here (see Chapter 7).

By evaluating the interview results, the thesis of e.g. Albers can be confirmed, which states that the main gain of knowledge lies in the verification or the validation. [15] This is concluded from the increased number of mentions (19 out of 27) of identification and the associated knowledge gain in the system verification and validation phase of the V-model. It was worth highlighting the result from section 4.3.14.3.1, according to which the early identification of emerging uncertainties was enabled by the underlying expert knowledge. The systematic review of the specifications can also be cited as a reason for the early identification, although this can only be attributed to the fact that cross-product development was upstream, which made a comparison and review possible in the first place.

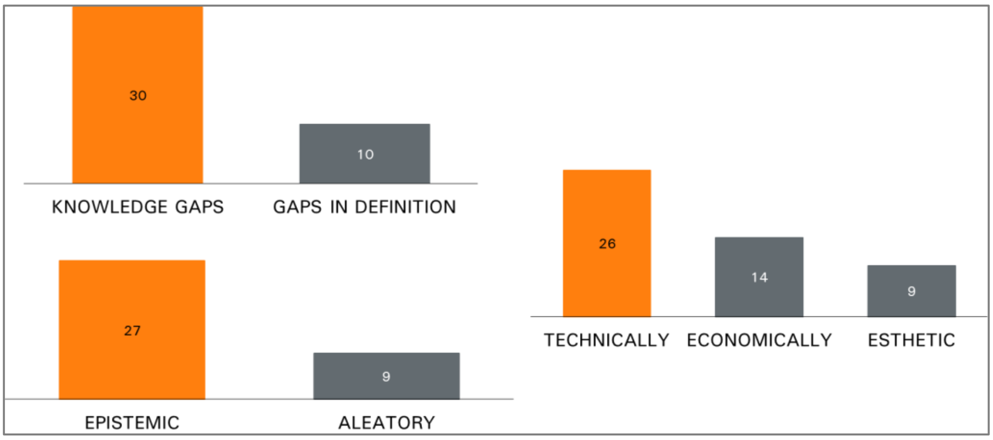

Figure 17: Summary of Figures 14, 15 and 16 with highlighting (orange) of the three dominant categories

When the uncertainties were filtered, all three parameters applied to 17 of 37 uncertainties. A closer look at these uncertainties revealed that for 12 of the 17 filtered uncertainties, emergent facts were responsible for the occurrence and identification of the uncertainty. Examples include the effect of resonances during the installation of the evolving system into the parent supersystem. Project management was also involved in the occurrence of the uncertainties, with schedule delays being the main reason at this point.

As a hypothesis to be validated, it can be assumed here that emergence, i.e., the interaction of several interacting parts of a system [16], can be considered as the main cause of the selected uncertainties. In Figure 17 the three models considered are again highlighted in orange.

The following aspects were not part of this elaboration:

- Despite the reference to existing models, it should be noted that the specific examples refer to only one company. However, since the focus of this work was on creating an initial assessment of the status quo, this is not to be considered critical. To validate the results, however, a further survey with a larger group of participants, focus groups and, if necessary, supplier companies would be useful.
- Another limitation, as with any type of survey, is a certain subjectivity of the results, which are based on the personal sensitivities, perceptions and assessments of the respondents on the respective day of the interview (daily form) and are related to their general acceptance of errors or willingness to take risks.

6. FURTHER STEPS AND FIELDS OF RESEARCH

Based on the results of the interviews and a basic literature research, fields of action are defined in the following, which serve as a basis for further investigations and optimizations. A distinction is made between activities that can be implemented in the short term and with little effort and a long-term perspective.

The four short-term follow-up activities listed below are to be derived as follow-up objectives from this initial elaboration:

1. Carrying out project monitoring to objectify the results obtained and to confirm, classify or relativize the subjective assessments of the respondents. The focus is on the current and future internal projects of the company under consideration.
2. A detailed analysis of the methods and tools already used to manage selected uncertainties identified in this elaboration (e.g., via more detailed interview questions)).
3. Estimation of the influence of known methods and tools in product development on the reduction of uncertainties by using proven methods and tools.
4. The CPM/PDD approach according to Weber [17] is to be investigated and applied to selected uncertainties. In doing so, it is to be examined whether there are concrete correlations and whether there is an intersection in the selection of uncertainties.

These possible longer-term follow-up activities aim to reduce uncertainties in project management. By introducing appropriate methods and tools, monitoring uncertainties, and ensuring that checklists are up-to-date, effective risk assessment and risk management can be achieved. This contributes to improved project planning and execution. Possible longer-term follow-up activities resulting from the findings of this elaboration could include:

1. Methods, models and checklists can be developed that enable early and targeted identification and assessment of project risks. This would allow uncertainties to be better identified from the outset. This with focus on a selection, of the uncertainties identified in the context of this paper, which have a major technical and economic impact on project success.
2. A monitoring system should be implemented to continuously monitor the identified uncertainties. A comprehensive literature review is necessary to identify and effectively use existing approaches and methods for monitoring uncertainties.
3. Permanent storage and provision of information are crucial to ensure that the checklist is up to date. Establishing a database or information system allows easy access to relevant data to keep the checklist up to date. These follow-up activities aim to reduce project management uncertainties. By implementing appropriate methods and tools, monitoring uncertainties, and ensuring the checklist is up-to-date, effective risk assessment and management can be achieved. This contributes to improved project planning and execution.

It should be noted that the reasons for different answers can also be traced back to a lack of theoretical background knowledge or a lack of detailed reflection on completed projects. This gives rise to a need for further investigation, which is to be pursued in the next step of the study.

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