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CRISIS SITUATIONS IN ENGINEERING PRODUCT DEVELOPMENT - A METHOD TO IDENTIFY CRISIS

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Abstract

An observational case study and an observation method are presented in this paper. The goal of the observation method is to identify, observe, document and analyse crisis situations in engineering product development teams. Crisis situations are characterized as unexpected or undesired situations with time pressure and pressure to act. The case study observes an academic student team designing and developing a racing car, as part of an inter-university racing car challenge. An introduction about case study design and a classification of the presented case study is given. The various steps in the observation method are described with the corresponding tools used in each step. Further, the application of this method is also explained and an initial framework of crisis situation is shown.

Keywords: Risk management, Human behaviour in design, Research methodologies and methods, crisis management, observational study

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1 INTRODUCTION

The process of engineering product development spans from the identification of needs to the development of products that can fulfil the needs. Typically, several kinds of crisis situations are encountered during this process. In product development a crisis is defined as an unexpected and undesired situation characterised by time pressure and pressure to act (Lindemann, 2009). Crisis situations in engineering product development need to be managed by the involved personnel (designers, manufacturers, etc.). Crisis situations are crucial because they are often the cause of turning points leading to paradigm shifts. Depending on the decisions taken and behaviour of the involved personnel, crisis situations and the ensuing outcomes are influenced accordingly. Despite their importance, there is little information about crises, their characteristics, causes, effects, etc. in the literature on engineering product development. This research is undertaken to fill this gap and consequently to better understand crisis situations in engineering product development. This is done by characterising crisis situations in engineering product development. On one hand, this research focuses on literature on crises in other fields, such as psychology, project management, economics, etc., and on the other hand, knowledge from industrial practice is gathered to gain deeper understanding about crisis situations. To achieve this goal, we plan to combine findings from literature from diverse fields with findings from observations of product development processes.

In this paper, a method is developed to identify crises in product development processes. The method is implemented on an ongoing case study of a student team, which comprises of Bachelor- and Master-level students from several streams of engineering at the Technische Universität München, designing and developing a racing cars as per the specifications laid out in an inter-university motorsport competition.

1.1 Literature on crisis situation

Crisis situations are researched in different fields: economics, psychology, political science, etc. Krystek (2007) defines crisis in economics as a subsistence threat, which can lead to unexpected and undesired loss. It can also be a threat to dominant goals. The result can be the extinction of a company or it can be a success (ambivalent result). This situation has a process character, which is time limited and has problems of control. Roloff (2010) defines a crisis situation as specific, unexpected, and non-routine events or series of events that [create] high levels of uncertainty and threat or perceived threat to an organization's high priority goals. Other similar definitions can be found in Burnett (1998), Briggs (2000), and Venette (2003). Beside company crisis, crisis is also differentiated into economy crisis and constitutional crisis (Neubauer, 2010). Though there is a wide spectrum of definitions and knowledge about crisis situations in other fields, few literature is found in the field of product development.

In engineering product development crisis situations can exist on technical, social, or organizational level. These situations do not have to cause the extinction of an industry, rather important goals (e.g. milestone or cost limits) cannot be reached. Examples are worker shortage (loss of important employees, e.g. team managers, due to sickness or enticement), technical issues (loss of production or unexpected results like the moose test crisis of Mercedes Benz A-class), or the lack of information due to communication problems or data loss (e.g. server crash or thievery).

1.2 Goals of the Case Study

One approach to fill the described gap about crisis situation in product development is an observational study. Crisis situations are well known for engineers. However, detailed descriptions of triggers, interactions, and influencing factors are missing. The observation of engineering teams does a first step to gain deeper understanding. Therefore, the main goal of this observational study is to characterise crisis situations in product development projects by identifying crisis situations and thereby, identify their causes, effects, and management. The case study has the following goals: (1) identification of crisis situations, (2) documentation of crisis situations, (3) evaluation of crisis situations, and (4) deduction and validation of hypotheses or indicators. To do these, a method is proposed in this paper and is currently being implemented on the ongoing case-study.

The identification of crisis situations is a critical point of this study. A crisis situation is normally recognized after the outbreak. The identification has the goal to undergo the whole process from initiation of the crisis situation, outbreak, and problem solving. After the outbreak or identification of

crisis situations, these situations should be documented in a standardized way to enable a high quality evaluation. The evaluation of the documented crisis situations should lead to detailed insights about the interactions of crisis situations. It should lead to assertions which can be generalized.
Finally, hypothesis or indicators for further investigations should be deduced. In follow-up studies the possibility of validation of hypothesis should be facilitated.

1.3 Structure of the paper

The paper is structured in four parts. Section 1 defines crisis situations in product development and the goals of the presented case study. Section 2 introduces the case study. Starting with the classification of the case study and possible obstacle with case studies, which have to be considered during the design and conduction of case studies. The main part of Section 2 is the developed observation method. It is describes step-by-step. Additionally the developed tools for the case study are presented. The section concludes with the description of the application of the case study and a brief introduction of the observation object (TUfast team) is given. Section 3 discusses the designed observation method and discusses relevant obstacles for this case study. Subsequently the evaluation the case study and an initial crisis model are presented. The paper closes in Section 4 with an outlook of the next steps of the crisis situations in product development research project

2 OBSERVATIONAL CASE STUDY

The following section describes the observational case study design, obstacles which have to be considered during the design and conduct of the observational study as well as the developed observation method. The case study design classifies the study based on literature. The obstacles were derived from literature and the design phase of the study. The design of observational study describes in a step-by-step fashion the method and the relevant tools for conducting the study

2.1 Description of the study and boundary conditions

Different basic types of case studies exist (Yin, 2014). The types are classified based on the units of analysis and the quantity of cases. Figure 1 depicts different kinds of case studies considering these two aspects.

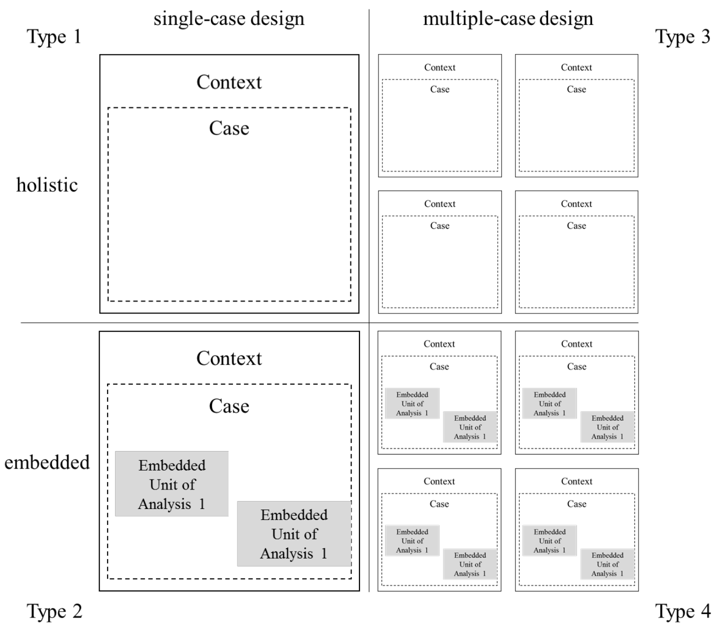

Figure 1: Basic types of Designs for Case Studies (Yin, 2014)

The presented case study and the developed method for the implementation together comprise a single case embedded case study (Figure 1, Type 2). In detail it means that a specific context and case with embedded units of analysis is analysed. The context is the TUfast racing team, which develops racing cars as part of the inter-university competition. Within this context, the case of the chassis

development team is observed, which describes the embedded unit of analysis (see Section 2.4). Based on Bortz *et al.* (2009) features of the case studies can be characterised in more detail. Firstly, it is a non-experimental study. The parameters are not specified by the observation team. It is intentional and also not possible to adapt the team structures, methods, or procedures. Secondly, it is a qualitative case study. Consequently, analytic induction is performed. With these conclusions are drawn from a particular case (TUfast) to more general case (crisis situation in engineering product development). Thirdly, it is a one-instance case study. The data come from a real case testing environment. With this it is an observational study and the goal is to generate data and identify causal dependencies. To summarise, the case study is a single case embedded qualitative non-experimental type.
Additionally the observers are not part of the team being observed, standardised tools will be applied and the study should be continued as a hypothesis study after the identification of crisis relevant hypothesis.

2.2 Possible Obstacles with Case Studies

During the development and implementation of the case study different obstacles have to be encountered. An obstacle is a situation, an event, etc. that makes it difficult for you to do or achieve something (Oxford University Press, 2014). In case of a case study this can be parameters, standards, or items. The following obstacles are identified from literature and during the development of the case study (see Table 1).

Table 1: Overview of possible obstacles during case studies

Obstacle	Description	Source
Ideal vs. real set-up	The planned test conditions do not match with the real case study environment.	Bortz *et al.*, 2009, p. 266
Interference of observation object	Interference with observation object may change the behaviour of the observation object and lead to different (faulty) results. Additionally: Halo-Effect, benignancy, astringency	Roth *et al.*, 1999, p. 140
Adjustment of tools	During the progress of the case study an adjustment of indicators may be needed due to new data or knowledge. Those iterations should be avoided for higher consistency.	Roth *et al.*, 1999, p. 139
Data acquisition/ selection possibilities	The kind of data acquisition used may influence the observation or interview Example: Video documentation can lead to reservation of the observation object.	Bortz *et al.*, 2009, p. 309
Secrecy	Secrecy may have influence on the publication of results and the observation possibilities.	Identified during case study design
Time for data collection/acquisition	Around the clock observations are expensive. Influencing factors are man-power, financial capital, or access to the observation object. In regard to these factors capacities for the observation should be calculated.	Identified during case study design
Evaluation and amount of data	Depending on the amount of collected data the evaluation can be work-intensive. The effort-benefit-ratio should be positive. Subjective interpretation of data by different observers.	Identified during case study design

2.3 Observation method

For the implementation of the case study an observation method is developed. The goal of the method is to systematically observe the behaviour of engineering product development teams and to identify and document crisis situations. The method has an iterative structure. With this, hypotheses about the behaviour of the teams in crisis situations are developed. The verification of these hypotheses can be done in a second observation loop or by observation of other teams within TUfast.

The method consists of eleven steps, which are divided into three parts depicted in Figure 2: preparation (white), observation (light grey), and evaluation (dark grey). These steps are followed in sequential order. In the following paragraph each step of the method will be described.

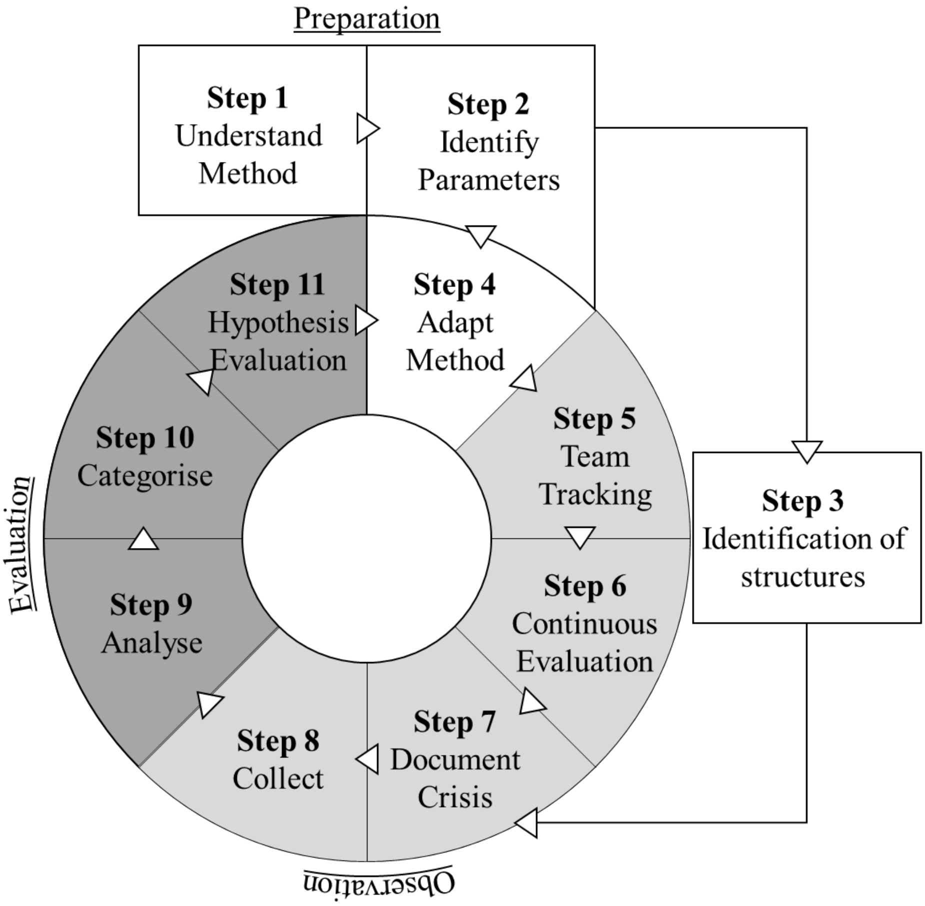

Figure 2: Graphical depiction of the observation method

2.3.1 Preparation

The preparation phase has the goal to identify the relevant boundary conditions (parameters), collect constant data, which are needed for the documentation of the crisis, and to adapt on one hand the method to the boundary conditions and on the other hand to integrate hypotheses which should be verified during the case study. The preparation phase has four steps. Steps 1, 2, and 4 should be run in sequence. The third step (Step 3) should be performed together with Step 2.

Step 1: Understand Method

The goal of the first step is to introduce the observation method. Before the first application, the method should be understood well. The goal is to avoid possible obstacles, which may occur during case study observations (see Section 2.2).

Step 2: Identify Parameters

The goal of this step is to identify the boundary conditions for the observation. Inputs for this step are information about the organisation and communication structure with (researcher ←→ observation object) and within the observation object. Therefore, it has to be clarified which media can be used during the observation, e.g. audio or video documentation or only written notes. Additionally the observation conditions should be clarified; access to team meeting or team communication, e.g. e-mails, protocols, or sketches and models. Also the identification of team specific meetings facilitate the observation. Output of this step is a list of observation requirements, which is needed in Step 4.

Step 3: Identification of structures

In this step the process and structural organisation of the examination object is recorded. This can be represented using organigrams, structural plans, and project schedules. This information is needed for the documentation of the crisis situation and will be explained in detail in Step 7.

Step 4: Adapt method
The fourth step has the goal to adapt the method to specific conditions identified in Step 2. Input for this step is a list of requirements. This step can also be used for iterations from Step 11. The derived hypotheses or indicators and tools are implemented. The preparation phase concludes with this step.

2.3.2 Observation

In the observation phase data collection is performed. Starting with the continuous observation (Team Tracking) and evaluation. Based on the tracking, crisis situations are identified, documented and used for later evaluation. This phase has four steps. The result of this phase is systematic documentation of crisis situations, which occur within the observation object.

Step 5: Team Tracking
The starting point for the observation is the Team Tracking. The goal of Step 5 is the identification of crisis situations within the observation object. The output of this step is a signal, which initiates the observation and documentation of specific crisis situation. The Team Tracking is divided into two parallel sub-steps: Team-Barometer and Checklists. The Team-Barometer continuously measures the team atmosphere. The Checklist is used for detailed observation of team meetings.

Checklist
The Checklist is used to evaluate team meetings. The Checklist is developed based on crisis indicators from literature (Espich, 2004; Lindemann, 2009; Töpfer, 1999). The input to the Checklist are team observations. During or after each meeting the observer fills out the Checklist. For this the observer has to attend team meetings. To reduce the effort, relevant meetings have to be identified (see Step 2). The checklist has 16 indicators listed in Table 2. Each parameter is rated on a four-step scale: unfulfilled (0), light (1), medium (3), heavy (9). Each step gets a factor from on a four-step scale (0, 1, 3, 9). The exponential increase of the factors has the goal to increase the influence of each indicator if it appears "heavy". The values of the indicators gets aggregated and is expressed in one number. The right evaluation is currently tested in a pilot study (see Section 2.4).

Table 2: Overview of Checklist indicators

Indicator	Source
Milestones overtime	Espich, 2004
Exceed budget	Espich, 2004
Extension of project duration	Espich, 2004
Activities stagnating at 90%-Ready-State	Espich, 2004
Critical goals are not reached	Espich, 2004
Additional tasks during project	Espich, 2004
Disturbed relationships	Espich, 2004
Unexpected or undesired events	Lindemann, 2009
Complex problems with high pressure to action	Töpfer, 1999
No experiences or algorithms to solve the problem	Töpfer, 1999
Approved strategies or mechanism do not operate	Lindemann, 2009; Espich, 2004
Interior restructuring is needed	Lindemann, 2009; Espich, 2004
Disorientation on all levels	Töpfer, 1999
Overextension on all levels	Töpfer, 1999
Situation seems unsolvable for all participants	Lindemann, 2009; Espich, 2004
State of paralysis is dominating	Töpfer, 1999

Team-Barometer
The goal of the Team-Barometer is to identify crisis situations by observing the team atmosphere. It is expected that a crisis situation changes the behaviour of team members.
The Team-Barometer is a questionnaire, which continuously helps monitor the team atmosphere. The factors of the Team-Barometer are based on literature on project management (Oberlender, 2000; Turner, 2009). It focuses on team efficiency and team management. With this it tracks the level of information, productivity, clarity of goal, team spirit, fun, and motivation.
To reduce the time for the observation objects the Team-Barometer is a multiple-choice questionnaire. Each question has a title, a short description, and six possible answers. The answers reach from "very low" to "very high". The query about the tasks is also done with the help of multiple-choice questions

but in the form of a matrix, since the observation objects do different tasks in different phases. It can be filled out in less than two minutes. The result of the Team-Barometer are graphs which can be used to depict the atmosphere of the team twice a week.

Signal

The results of Checklist and Team-Barometer can be used to identify individual crisis situations. The Signal has the goal to summarise the tracking data into one value. If the Signal exceeds a threshold, then the documentation of the crisis situation (the identification of the right threshold is presented in Step 6) starts. For details see Step 7. Figure 3 depicts a schematic illustration of the Signal.

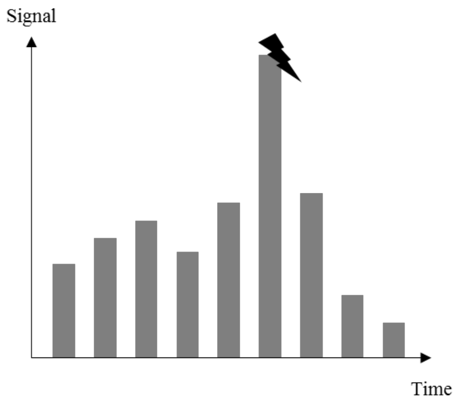

Figure 3: Exemplary depiction of the Signal

Step 6: Continuous Evaluation

The goal of this step is the continuous evaluation of the data from the Team Tracking. Within this step the signal is regularly checked. The input for this step is the signal from Step 5. If the signal deflects, then Step 7 starts.

Another important goal of this step is to adapt the signal of Step 5. When a new team is observed with the method, less knowledge exists about critical values of the signal. A continuous adjustment of the signal may be needed. The adjustment can be enhanced with team interviews to figure out the status of the team and a crisis potential.

		Five steps of crisis documentation				
		Indicators	Causes	Effects	Progress	Solution
Five levels of crisis analysis	Content & Process					
	Information					
	Organi-sation					
	Communi-cation					
	Psychology					

Figure 4: Documentation template for crisis situations based on (Töpfer, 1999)

Step 7: Document Crisis

If Step 6 detects a crisis situation, then Step 7 starts. The goal of this step is consistent documentation of the detected crisis situation. Another input is the data from Step 3. With this the consistent documentation should be enhanced, since the documentation is adapted to the use case. The step follows a standardised documentation process, which is based on the crisis model of Töpfer (1999). A general description is given in Figure 4.

Step 8: Collect Situations
The goal of this step is a support to a consistent documentation. Within this step all identified and documented crisis situations will be digitally collected using supportive tools such as MS Excel.

2.3.3 Evaluation

The evaluation phase analyses the documented crisis situations. Causes, effects, approaches to overcome, and impacts of crisis situations should be identified. Based on this knowledge, hypotheses are generated or verified. Equally a crisis situation model will be set-up in future work (see Section 4).
Step 9: Analyse
The inputs for this step are the collected crisis situations from Step 8. The goal of this step is to figure out similarities and differences of the crisis situations. The analysis focuses on causes, effects, impacts, influencing, success, and failure factors, as well as used approaches or methods to overcome the crisis situation, and the human behaviour of the observation objects. Based on these results a generic crisis model is established and applied (see Section 4).
Step 10: Categorise
Based on the crisis models of Step 9, a categorisation of the situations is done. The categorisation follows crisis categorisations of (Zelewski, 1994; Lindemann, 2009). With this crises are categorised in terms of varying scales of pressure to act (deviation from goal and time left to solve) and phases of the crisis situation (potential, latent, and acute). The model is depicted in Figure 5.

		Phase of crisis situation		
		Potential	Latent	Acute
Pressure to act	Low			
	Aver age			
	High			

Figure 5: Crisis situation categorisation model based on Lindemann (2009) and (Zelewski, 1994)

Step 11: Hypothesis Evaluation
In the final step of the method, hypotheses are derived from the collected data. The deduction depends on the experience of the observers. Insights from Blessing and Chakrabarti (2009) are used for developing research questions and hypotheses.
In this step, hypotheses can also be reviewed for approval or negation. Furthermore this step can be used to derive indicators related to hypotheses. These indicators can be integrated in Step 4 when a new observation cycle starts.

2.4 Application of the method: TUfast team

For the first application of the method, the TUfast e.V. Racing Team (TUfast) team of the Technische Universität München has been chosen. TUfast is a student product development team. Each year the team designs and develops two racing cars; one powered by an internal combustion engine and the other by an electric motor. The team has around 74 members and is structured into the following working groups: management, chassis, suspension, combustion powertrain, electric powertrain, and organisation. (TUfast, 2014)
The product development process of TUfast has been chosen because it is linked to the same university as the authors and therefore, access to all levels of information is relatively easier. Moreover, the team comprises members from multiple disciplines of engineering, working together for several months (ca. 12 months) to develop two racing cars from the given specifications. After the cars are developed, they will compete against teams from other universities on a racing track. The development process is also funded by automotive industries and consequently, the stakes are high. In other words, this case study can be taken equivalent to product development in industry.

The observation started in December 2014 and will conclude in October 2015. The observation is done by a team of 2 students. Within this case study, the chassis team and the team leaders (leaders of the groups) are observed. The chassis team has around 10 team members. All members of the team support the observation by regularly filling out the Team-Barometer. The Team-Barometer ascertains the team status weekly. For data collection the questionnaire function of google forms is used (Google, 2014). Additionally, the following team meetings are also observed: the chassis team meeting and the team leaders meeting. The meetings are documented using protocols, one each by the TUfast team and the observers. Both these influence the checklist (see Section 2.3.2, Step 5). The observers have access to the following data of the TUfast team: protocols of meetings, data of designs, e-mail communication, and interviews with team members.

3 DISCUSSION

This section discusses the application of the developed method, expected results, and case studies in product development.

With this research it is expected to gain insights into crisis situations during the development of technical products. To gain deeper insights it would be better to observe an industrial team. However, this is not straightforward because industries are reluctant to share crisis situations due to their confidentiality and sensitiveness. This was one of the reasons why a student-based product development team was chosen for the observation.

The development of the observation method was based on literature from 'design of experiments'. Main obstacles in this case study were: influence of the observation object, amount of data, and time for data collection. Since it was needed to survey the TUfast team, the influence of side-effects could not be avoided. It was less problematic with the Team-Barometer (see Step 5 in Section 2.3.2,), since it was done continuously and consequently, the observation object became familiar. The interviews had more issues because there were direct interactions with the team. To counter the influence of side-effects in crisis situations, attempts were made to document the situations as much as possible without any assistance from the observation objects. Interviews were carried out retrospectively, if needed, to better understand crisis situations without influencing the subjects or the situations. However, the interference of observation objects could not be discounted but was minimised to the extent possible.

Although a lot of data was collected from this study, given the constraints including time, analysis rigour, etc. it was not possible to investigate all the data. For these reasons, the continuous evaluation of e-mail communication was excluded. However, this data source can be used if detailed evaluation is required. When setting up a case study, researchers have to evaluate cases by accounting for the types of both sources and contexts.

Finally, the time for data acquisition was an important boundary condition. It depended on two parameters: equipment allowed to be used and work capacity. Even though the observation was a fulltime project a 24x7 observation was impossible. Analysis of audio and video data, e.g. with the help of verbal transcriptions, is more time consuming than the observation itself. For this reason, the Team Tracking was set up. The Team-Barometer should gave adequate insights of the team atmosphere. With the Checklists only few meetings were observed to reduce the observation effort and maximise the time for data analysis.

One of the biggest challenges of this case study was the transformation from subjective data into a form that can be analysed and interpreted in a generic way. In general, a crisis situation is perceived differently by each person. This perception is influenced by mental situation, standard of education (e.g. undergraduate, graduate), and work experience (beginner, experienced, or expert) of individuals. These aspects need to be accounted by the observers in order to gain insights into crisis situations and their documentation. These aspects have to be taken into account by adapting evaluation scales like the Team-Barometer or Signal during the pilot phase of the case study. Initially it is not possible to know the value of the Signal or curve behaviour of the Team-Barometer corresponding to a crisis situation, and therefore, only assumptions can be applied, for example:

- A slump in motivation or clarity of the goal curve indicates a crisis situation.
- If several curves of Team-Barometer slump, then a crisis situation is highly likely.
- If the Checklist parameters have large values, then a crisis can happen.

The evaluation of the Team-Barometer indicators, the characteristics of the Checklist parameters, and the calculation of the Signal have to be done in retrospective and by accounting for individual cases.

4 OUTLOOK

Further steps in this research are the development of a descriptive model for crisis situations in technical product development. The model will be used to evaluate the collected data (see step 9). This crisis model will be built from other models of crisis situations of Töpfer (1999) and Badke-Schaub and Frankenberger (2003).
Further, to gain more knowledge about crisis situations, their influencing factors and success/failure factors in industrial practice, an interview study with product designers and developers from various industries is currently being conducted. Industrial partners to carry out observational studies in industry, are also being identified.

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