



AN EXPLORATORY STUDY OF CRISES IN PRODUCT DEVELOPMENT

C. Muenzberg, K. Gericke, J. Oehmen and U. Lindemann

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1. Introduction & initial situation

In April 2010, the Deepwater Horizon oil rig exploded in the Gulf of Mexico. The explosion killed 11 workers. In order to stop the oil outflow, the workers attempted to activate the blowout preventer, which failed. As a consequence, more than 779 million litres of oil streamed into the Gulf of Mexico during the following 4 months, causing the biggest oil spill in history. Besides the enormous environmental destruction and the death of 11 men, the Deepwater Horizon crisis accrued a high image loss for the oil rig operator. The direct cost of the crisis summed up to 35.6 billion € [The Economist 2015].

Crisis, as described above, happen in every sector, including product development. They are independent of the size of the enterprise. Prominent examples are the A-Class "moose test" crisis [Andrews 1997], [Töpfer 1999], the Boeing Dreamliner battery crisis [Mouawad 2014], reception problems of Apple's iPhone 4 [Ionescu 2010], [Helft 2010], or most recent the Volkswagen "emissions cheating" crisis [Russel et al. 2015]. The characteristics of these crises differ. In particular, their causes and effects differ clearly. The causes can be internal, e.g. personal negligence or construction faults, or external, e.g. legal changes or natural disasters. The effects are as diverse as the causes. They range from safety, environmental disasters, to economic meltdowns, threatening a company's success, which could lead to bankruptcy. However, these situations also have similarities. With a crisis, the workload of the involved people and their stress levels increase. Identifying these similarities for a characterisation of crises in product development is the main goal of the presented research work. Our first research question is:

1. How can crises in product development be characterised?

Literature on crises in economic science is the most relevant literature for the characterisation of crises in product development, e. g. [Mitroff et al. 1987], [Lalonde 2007], [Regeister and Larkin 2008], [Kor and Sikdar 2014]. These works focus on organizational crises. Literature on crises in product development is lacking, which leads to the absence of crisis-specific design support [Münzberg et al. 2015].

We conducted an explorative interview study to address the first research question. In this study 15 experienced design engineers were interviewed about their experiences with crises. We documented their understanding about crises and their chosen approaches to overcome crises. This expert knowledge supports the development of a crisis-specific design support. Thus, our second research question is:

2. What are success factors for effective crisis solving in product development?

Various detailed approaches for the development of technical systems exist, such as Engineering Design (Konstruktionslehre) from Pahl/Beitz [French and Council 1985], [Pugh 1991], [VDI 1993], [Roozenburg and Eekels 1995], [Ehrlenspiel and Meerkamm 2013], [Pahl and Beitz 2013]. Applying systematic design approaches increases the project success, diminishes the time of product development

projects [Hales and Gooch 2004], [Graner 2013], and may help to reduce the likelihood of a crisis occurring. But the approaches lack guidance on how to effectively address crises. In this paper, we identify success factors for effective crisis management from the interview results, by reflecting them against product development success factors [Gericke et al. 2013]. We propose these as a design support tool for crises, which is suitable for industrial practice.

By answering the two questions, this paper contributes to theory by identifying "context factors", which characterise features of crises, and by providing a product-development-specific definition of crises. Furthermore, we present examples of crises from industrial practice. These situations illustrate the varied nature of crises. To support industrial application, we present success factors for efficient crisis management. These factors are starting points for the development of a crisis-specific design support. The following Section 2 briefly introduces existing crisis definitions and the foundations for the description of the "context factors" to characterise crises. Section 3 describes the research design of the interview study. In Section 4, crises are characterised and example situations are presented. Section 5 focuses on success factors. Section 6 closes with a discussion and conclusion, examining the answers to the research questions and developing a novel definition of crises in product development.

2. Definition and characterisation of development situations

A crisis is generally defined as "an unstable and crucial state of affairs in which decisive change is impending, especially one with the distinct possibility of a highly undesirable outcome." [Merriam-Webster 2015]. More specific, Lindemann defines a crisis in product development as "a situation, which is caused by undesired and unexpected events. These events are connected with high time and result pressure." [Lindemann 2009]. This definition is the basis for the following study and will be extended for product development in the conclusion in Section 6. Please see Münzberg et al. [2015], for a more detailed review of existing literature on crises in product development.

Based on the investigation of flawed products and their design process, Hales and Gooch present a concept of five levels of resolution to analyse design tasks, shown in Figure 1 [Gericke et al. 2013], [Hales and Gooch 2004]. The model contrasts five levels of resolution (macroeconomic, microeconomic, corporate, project, and personal) in the engineering design context. The goal is to describe influences on design projects in order to pre-empt their consequences [Hales and Gooch 2004]. Gericke et al. [2013] compiled 239 factors influencing product development based on a literature study. The subsequent analysis of crises focuses on these factors compiled by Gericke et al. [2013], describing the corporate, project, and personnel level according to above mentioned Hales and Gooch's categorisation of context factors. We omit the macro- (environment) and microeconomic (market) level due to the engineering focus of this paper. The selection of context factors bases on the results of the interview study and incorporates additional findings from a previous research, i. e. literature review [Münzberg et al. 2015].

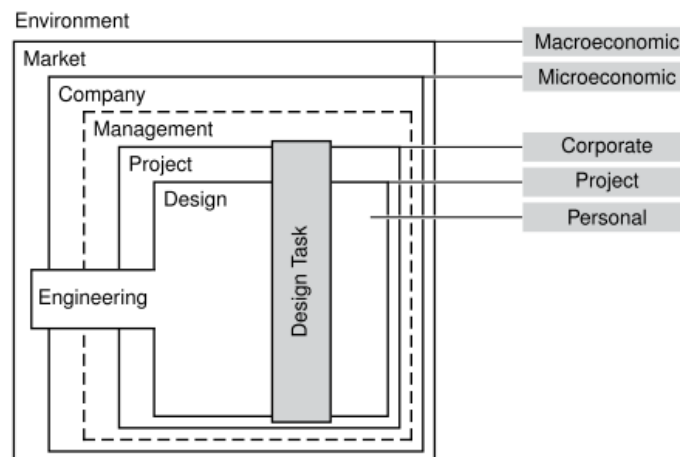


Figure 1. Level of resolution for design tasks from Hales and Gooch [2004]

3. Research design

The main goal of this research is to identify similarities of crises enabling a characterisation thereof by analysing the context of the situations. i.e. to distinguish crises from regular development situations. To achieve this, we conducted semi-structured expert interviews enabling a better understanding of crisis situations from a practitioner's point of view [Bogner et al. 2009], [Yin 2014].

We used data from 15 interviews with experienced designers, who recently faced crises during their project work, to achieve this objective and respectively answer research question 1. The participating designers are from the areas of production of machine tools, printing machines, automotive suppliers, and other multinational engineering companies. For the interviews, we used a systematic guideline with the following topics:

1. General information
2. Crisis characterisation
3. Crisis resolution approaches
4. Conclusive questions

Prior to the study, we tested the interview guideline with three persons. One test was performed with an experienced design researcher. The other tests were done with designers from industry. Based on the feedback from these tests, we refined the guideline before conducting the interviews. The interviews lasted between 60 and 90 minutes. We conducted face-to-face or telephone interviews to collect the data and documented them with hand-written notes.

All interviews followed the same procedure. In the beginning, we asked the interviewees to introduce themselves (Part 1: General information) to determine the background of the interviewees (work experience, stages of life, work environment). Afterwards, we presented a definition (adapted definition of Lindemann) for a crisis. Ensuring that all participants have the same common understanding of the terminology, we discussed possible modifications (Part 2: Crisis characterisation). These results were used to elaborate the characteristics of a crisis. The third part (Part 3: Crisis resolution approaches) was the main part of the interview study. The participants described one or two crisis/crises. Thereby, the following topics had the main priority:

- initial situation of the crisis
- causes and effects of the crisis
- crisis accomplishment approach
- involved persons
- result of the crisis resolution process
- consequences of the crisis

After the description, we discussed the general crisis resolution processes with the interviewees. In this part, the participants were asked to describe their personal crisis resolution experience. First, it was discussed if their company provides any systematic support (i. e. process models or methods) for the resolution of crises. Second, the participants reflected their approach and assessed its success and were asked to think of possible adaptations in retrospect. Third, general success factors and hindrances were discussed. Finally, the interviewees were asked for general categories of crises in product development. In the last part of the interview study (Part 4: Conclusive questions), questions regarding other contact persons for crises, possible check backs, and further adaptations of the initial definition were asked.

Afterwards, we analysed each interview. The hand-written notes were digitalised and complemented based on memory minutes. Each interview was documented in a structured spreadsheet. The structure of the spreadsheet was identical to the structure of the interview guideline. For the results of this paper, we further evaluated the interview data about crisis definition and success factors by data categorization following Roulston [2010]. The data about crisis definition were compared with the definition of Lindemann [2009]. These data, the knowledge out of the literature study, and the work of Gericke et al. [2013] were used to characterise crises and identify the context factors relevant for characterising crises. The data set of the success factors was coded to identify redundancies. Then, the results were categorised following the levels of resolution of Hales and Gooch [2004].

4. Findings Part I: Example crises and context factors

This section presents exemplary crises identified in the interview study. Furthermore, crisis-specific context factors identified during the interviews are analysed, based on a generic list of factors influencing product development (from Gericke et al. [2013]). The objective is to find a subset of context factors that allow a distinction of a crisis from a regular (potentially "stressful" or time-critical) development situation.

Example situations

This section gives an overview about three (out of the 15) exemplary crises from industrial practice, which were reported by participants of the interview study. These situations show the diversity of crises. Subsequently, crisis solution approaches reported by the interviewees are described. The descriptions of the crises have the following structure:

1. Environment and causes for the crisis
2. The actual crisis
3. Effects of the crisis

The first example presents a crisis during the product development process. The crisis occurred in the transition from a pilot-project to first series production. In the second example, a company faces the introduction of a disruptive technology by a competitor. The third example presents a crisis which occurred after product launch.

Example 1: Underestimated criticality of components

This crisis occurred in the pre-product development process of a large automobile original equipment manufacturer (OEM). During a test, a disturbing noise occurred. The company was aware of this problem but did not rank it as critical. In earlier tests, the disturbing noise did not occur since the engineers did not properly adjust all components for this test setup. In later tests, the adjustment of components was set to the final setting. In these tests, the disturbing noise occurred. The disturbing noise was assessed as critical; therefore the product could not be released. At this time, the release date approached and regular design changes were not possible anymore. This resulted in an enormous time pressure with only few options for handling the situation.

The company has a structured crisis management process. In order to solve the problem, a crisis team with up to 25 employees and external support (e.g. suppliers or academic research partners) was set up. In the beginning, the crisis management team followed a sequential approach, but later a parallel problem analysis and solving process was conducted due to time pressure. To the time of the study, the crisis was not solved. Given the crisis will not be solved, the effects will be negative assessment of the employees, lost profit, and danger for the company's existence.

Example 2: Appearance of a disruptive technology

In a large electronic and electric product supplier, the top management reported that a competitor developed a future-oriented manufacturing process. A team of ten designers developed the technology over a period of three years at the competitor's firm. Thus, the company had a development advantage of 30 man-years. In this unexpected situation, the top management considered four scenarios:

First, only the competitor is able to develop the technology to a mature stage while the own company is not able to do so. This would be the maximum credible accident (MCA). As a consequence, the market-share of the company could drop by 80 % in the next years.

The second scenario anticipates that both companies do not develop a new technology. This scenario would cause no further critical effects for the company.

The third scenario describes that the own company develops within this new project a new technology and the competitor does not. With this, the crisis would become a profit situation.

The final scenario foresees that both companies develop a new technology. This would increase the pressure on the company but the company would have a solution and could respond to the competitor's technology.

The top management assigned a new team to do research to figure out the potentials of this new technology. With the four developed scenarios, the crisis management team had the task to catch-up with the competitor and evaluate the possibilities of the appearance of the new technology. With this, a high time and result pressure as well as pressure to act are exposed to the team. The team had no experience with the new technology and should get started immediately. Additionally, the team reported on a monthly basis to the top management, enabling them to make assessments about the success of the new technology and decide about follow up actions.

The team decided to follow a simultaneous approach of the tasks. A technology screening, procurement of equipment, and a cost and marketability assessment were conducted. The team worked for eleven months. After this period, the top management did a final assessment. They decided that this new technology is not promising and will not disrupt the market. Afterwards, this estimation was right and the crisis was successfully overcome. With this, the second scenario (no new technology is introduced into the market by both) occurred.

The effects of the crisis were multi-pronged. On the one hand, the working pressure increased on employee-level. On the other hand, the importance of the involved employees increased and they had the possibility to profile themselves. Furthermore, the company could have lost big market shares during the crisis. Because of performed actions, the negative anticipated effects could be avoided.

Example 3: A supplier with an unexpected quality problem

This crisis was caused by major quality problems of a mass product of an automotive supplier. An OEM reported a quality problem (failure of component during use-phase) with one of the components delivered by the supplier. The OEM had already started corrective actions (cause analysis, turnover correction). The OEM demanded from the supplier to identify the problem within the next eight days and to present a solution within two weeks.

The supplier is located in Germany, the OEM in Japan. The geographic distance, cultural differences, and language issues posed further obstacles beside the technical problem. Also the behaviour in the crisis differed. While the German designers kept calm, the Japanese engineers became hectic in the crisis. The distance became a special challenge, as a fast exchange of material good was impossible.

A crisis management team consisting of three designers was set up by the supplier at the German headquarter. 3-4 designers from the OEM in Japan supported the German team. The crisis team received images and later via mail an example of the failed product. Using documentation of the failed product, the team tried to identify the cause of the failure. This was followed by quality controls (failure-tree-analysis) and tests. Based on this information, the team started to formulate assumptions and began with laboratory experiments. The assumptions were prioritized and tested. Parallel to the problem analysis and solving process, the supplier stayed in close contact with the OEM via telephone conferences. The goal of this communication was to signal trust, calm the customer, and to involve the customer into the problem analysis and solving process.

With this approach, the company overcame the crisis. The consequence of the crisis was that the supplier lost several thousand Euros per month during the crisis. During the crisis management process, the OEM used a competitor product, which caused further monetary losses for the supplier. However, the successfully solved crisis resulted in an improved and closer collaboration of the two companies (supplier and OEM), and weekly telephone conferences were maintained.

Characterisation of crises

For the identification of context factors of crises, the 239 factors compiled by Gericke et al. [2013] were used. The analysis bases on the gained knowledge of literature review [Münzberg et al. 2015] and the conducted interviews. Overall, 15 cases were analysed from which three were presented in the previous subsection. Additionally, for the identification of the context factors, the effects of crises were considered. Main effects of crises are danger to human life, or high cost to the organization due to management effort or loss of image (and subsequent loss of sales).

Table 1 presents the identified context factors. Furthermore, the table shows a brief derivation of the factors. The context factors are: project risk, priority, pressure to succeed, motivation, individual time

pressure, reward & recognition, management support, coordination and division work, as well as type of project control.

The appearance of the identified context factors was highly consistent and prominent across all 15 cases. Compared to this, the appearance or significance of the factors varies significantly in a regular development situation, depending on the particular project.

Table 1. Overview of context factors of crises

Project risk
high result and time pressure, unclear information situation → high project risk
Priority
far-reaching consequences (e. g. bankruptcy, product failure, danger of live, high costs), high result and time pressure → high (project) priority
Management support
far-reaching consequences → high project risk, priority → management attention → management support
Degree of motivation/morale, Project motive, Motivation
far-reaching consequences → high project priority for damage prevention → management attention → high motivation
Reward and recognition
high project risk & high project priority → high internal and external recognition → high reward for crisis solvers "fire fighters"
Pressure to succeed
far-reaching consequences → project "must not " fail → high pressure to succeed
Individual time pressure
high result and time pressure → higher work load and working hours → high individual time pressure
Coordination and division of work
high project priority & high risk → decoupling from "daily business", need of special competences → special coordination and division of work, e. g. task force or fire-fighting team
Type of project control
management attention and support → high motivation decoupling from "daily business" → direct report to and control by management control → special type of project control
Legend: → = results in...

The analysis of the context factors of crises shows that the different factors interacted in the analysed examples: It is found that the project risk of crises is higher compared to regular development situations.

Since crises are unexpected, undesired, and have high time pressure, the information situation is unclear. This lag of information leads to decisions under high uncertainty. Furthermore, the unexpectedness and undesirability lead first to higher recognition and, if the situation is solved, to higher reward for the problem solvers (e.g. promotions or at least recognition by superiors). The higher recognition also comes from result pressure. If no solution is found, the situation can escalate even further. Because of this, the project risk and pressure to succeed are higher and lead to higher recognition of the crisis. The impact of failed crisis resolution is higher compared to failure under regular development situations. The result pressure also leads to higher motivation of the involved persons, higher pressure to succeed and increased priority in the organization. The involved persons want to solve the situation to prevent worse happening to themselves, their project, and company. The higher motivation in crises also comes from the higher pressure to succeed. This pressure is also connected to higher priority. The higher priority again comes from the higher effects of a crisis compared to a regular development situation. The time pressure and the pressure to succeed lead to higher individual time pressure. The analysis of the 15 interviews showed that, unsurprisingly, involved people have higher workloads and longer working hours.

Management support is one of the most important factors. Management support bases on the high project risk, pressure to succeed, and priority. All these characteristics lead to high management attention, as well as management backup for decision making and resource allocation to the team. Finally, it was found that development teams solving crises are detached from the regular organizational structure. These teams are formed out of existing teams or are set up completely new. In general, the teams consist of the best available experts equipped with monetary resources and equipment. It was also found that most of the crisis management teams directly report to the top management to keep it informed and allow quick decision making.

5. Findings Part II: Success factors for effective crisis solving

Through the interview study, we identified 56 success factors. Cambridge Business English Dictionary [2015] defines success factors as: "One of the most important things that a company or organization must do well in order for its business or work to be successful."

These factors are also categorised according to Hales's [2004] levels of resolution for describing product development context. Since we focused in the interview study on internal crisis solving, all factors can be classified on corporate, project, and personal level. The results are shown in Table 2.

The classification shows that most of the identified factors refer to the project level, and here in particular to project management. On corporate level, 4 factors are identified. On personnel level, we only identified factors in the category "relationship". Many of the identified factors are also found in project management literature (e.g. [Project Management Institute 2008]). In the following, we describe a selection of the identified success factors (see Table 2) in more detail.

- "Emotional influence on the team by the team leader" and "Situative use of emotions": The study identified that the team leader is one of the most important persons. He or she decides the strategy, is the link between the crisis solving team and third parties, mainly defines the team culture and the team's communication behaviour. Emotional influencing team members can be key for successful crisis resolution. Depending on the situation, the team leader gives encouragement or motivates the team. For this, the team leader has to be sensitive to the mood and needs of his team.
- "Keep aloof" and "Do not personally overreach": It is important to keep the balance between the crisis and personal live. Therefore, the designers should not get completely absorbed by the crisis and overly neglect their personnel needs. By doing so, the designers can increase their performance level during prolonged crises.
- "'Careful' openness": This characteristic relates to sharing information with third parties. It is import to speak the truth. Lies and half-truths make the situation worse. But it was mentioned that the crisis solving team has the possibility to not disclose all available information and communicate only information, necessary at that point. The practice walks the fine line of giving enough but not too much information. Only experienced team members should use this approach.

- "Stay in motion": The team should always work on tasks to advance the crisis solving process. It is important to identify possible solution processes and to implement them instead of doing nothing and passively waiting for developments to unfold. In crises, decisions have to be made (see justified decisions) and implemented, even under significant uncertainty.
- "Justified decisions": The information situation is often unclear in a crisis. Decisions have to be made without the possibility to double check or review the decision with all team members. Because of this, it is important to justify the decision made. Decision makers should explain their approaches and their motivations. This helps to evaluate the decision and allows the other team members to understand their task and the chosen strategy. But most importantly, decisions have to be made even if their outcome is unclear.
- "Fresh minds": In one of the identified crisis solving teams, a graduate student was part of the team. His task was to support the team. He proposed new methods, which had not been used by the team before.

Table 2. Classification of identified success factors to resolve crises, based on design context checklist by Hales and Gooch [2004]

Corporate level (4)	
good corporate culture	support of top management
securing sufficient capacities	support with decisions making by top management
Project level (45)	
clear, short, quick, and timely communication	stay in motion
identification of different solution approaches	reflection
good analysis (hypothesis & wirkmechanismen)	thinking in alternatives
systematic, transparent problem solving approaches	visualization
managers should give clear targets	avoid scaremongering
emotional influence of the team by the team leader: situative use of emotions	stay cool and keep calm
team leader should show trust to his team members	do not say wrong things, but do not tell the untruth
experienced and authentic team leader	ensure sufficient capacities
attention to the key role of the team manager	leadership
honesty	trust
praise	clarify misunderstandings as fast as possible
confirmation	good project management (e.g. planning)
stable living situation	realistic and clear targets and targeted work
trust on all levels	regular project meeting
do not personally overreach	justified decisions
keep aloof	team work and team composition
to give his/her best	experienced team members
recognize need of help timely	coaches
flexibility	fresh minds
"careful" openness	team should be confident to solve task
motivation	take responsibility
ability to work under pressure	training of challenges to be prepared for crises
team spirit	
Personnel level (7)	
network: colleagues, external partners	start early communication
reliable network	experience exchange
communication with the right persons	communication with the customer
early integration of all relevant partners	

6. Discussion and conclusion

In the presented research, we focused on the characterisation of crises in product development. Our two research questions were:

1. How can crises in product development be characterised?
2. What are success factors for effective crisis solving in product development?

The two questions were answered based on an interview study with designers from industrial practice. Three major results were achieved: The first result is a collection and documentation of 15 examples of product development crises in industrial practice. In this paper, three exemplary situations were briefly described.

It is proposed to divide crisis in more specific subcategories to allow better support. Based on the findings, it is proposed to distinguish crises depending on their occurrence before (type 1) or after (type 2) product launch. This differentiation is made through the effects of a crisis. Type 1 situations occur primarily beyond public perception. Furthermore, the crisis management team already exists in most times. Vice versa, the public notices type 2 situations. Additionally, a crisis solving team has to be constituted.

The second result is the identification of nine context factors for the characterisation of product development crises. They base on the factors influencing product development compiled by Gericke et al. [2013]. These nine factors are distributed on two levels, project and corporate level: On the project level, they are: project risk, priority, pressure to succeed, project motive, reward and recognition, management support, coordination and division of work, type of project control, and motivation. On the corporate level, one factor is degree of motivation/morale. On the personnel level, the identified factor is individual time pressure. By evaluating these factors, it is possible to distinguish if a specific design situation is a crisis, or merely a regular "stressful" development situation. Evaluating the interviews, it was found that the identified factors appeared consistently and with high frequency. It is equally important to mention that other context factors may also be relevant. Further research is required to evaluate whether the identified factors are relevant for describing crises or whether they just apply for individual cases. With these two results, the first research question is answered.

The third result is a list of 56 success factors for dealing with crises. The success factors were described on the levels of resolution for design tasks from Hales and Gooch [2004], similar to the context factors. Most of these success factors can be found in project management best practice. However, the list can be seen as one tool for designers to prioritize and decide on organizational structure and processes to solve crises efficiently. Furthermore, it is a valuable starting point for developing a design support toolbox for designer to overcome crises in product development. With this result, the second research question from the perspective of designers in industrial practice is answered. This result should be matched with results about success factors in project management.

Further based on these findings and building upon the definition of Lindemann [2009], we propose a revised definition for crises in engineering product development:

A product development crisis is an exceptional situation. The situation has an impact on the individual team members, is limited in time, and has ambivalent outcome (the possibility for both a positive as well as disastrous outcome). It has negative connotation. The crisis is caused by undesired and unexpected events. These events are associated with high time and result pressure.

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Christopher Muenzberg, M.Sc.
 Technical University of Munich, Institute of Product Development
 Boltzmannstr. 15, 85748 Garching, Germany
 Email: muenzberg@pe.mw.tum.de