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Crisis Situations in Engineering Product Development: Elaboration of Principles for effective Crisis Solving

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Abstract

Every organization is threatened by unexpected and undesired events that cause crises. These crises are connected with high time and result pressure. In product development, methods to cope systematically with crises are only available on an abstract level. To support developers in solving crises, methods have to be provided. Because applying methods in product development increases the success of technical solutions. Hence, this paper aims at elaborating principles to enhance effective crisis solving. The paper focuses on two research questions:
1. Which factors differentiate crises in other fields from crises in engineering product development?
2. Which methodical approaches can be identified in other fields and transferred into engineering product development?
For that purpose, procedures and methodical approaches of organizations beyond the technical domain, whose daily routine contains complex and challenging tasks, are observed and analyzed. Communication and decision making in crises are emphasized. To generate expert knowledge of chosen organizations, employees of an organization acting in the aviation sector are interrogated in guided interviews. Furthermore, fire fighters are observed in organized workshops and practical exercises. In addition to comparing crisis definitions, methodical approaches are identified and transferred into the context of product development. As a result, 14 principles to cope with crises are framed, which are classified into the following clusters: procedure, communication, human, and training. This paper contributes a holistic set of principles to support engineers in crises. Because every principle bases on approaches identified in practical crisis solving.

Keywords: Crisis, Decision Making, Problem Solving, Principles, Time Pressure

1 Introduction and initial situation

In 1997, a test driver overturned an A-class during a high-speed evasion maneuver called moose test. Massive reactions in the media and public pressure forced Daimler-Benz to improve stability expensively. Furthermore, the delivery of cars had to be stopped for 15 weeks. Due to excellent crisis management and proper communication, the relaunch of the A-class was successful. (Töpfer, 1999)

This example shows that even global companies are threatened by crises. To cope with crises, organizations have to challenge complex dynamics and individual characteristics. Companies situated in different fields delve into crisis management and develop procedures and aids (Puttenat, 2009). In product development, methods to cope systematically with crises are only available on an abstract level (Albers, Burkardt, Meboldt, & Saak, 2005; Lindemann, 2009).

Following Lindemann (2009) in the context of engineering product development, crises are caused by unexpected and undesired events. The situation is connected with high time and result pressure (Lindemann, 2009). Crises are time limited. In addition, their outcome is ambivalent. That means that the situation can lead to success or result in a catastrophe. In companies, crises are generally negatively connoted. Hence, persons concerned focus on negative impacts (Krystek, 1981, 1987). Every person perceives the crisis subjectively as the situation has individual importance (Sonneck, Kapusta, Tomandl, & Voracek, 2012).

As both processes and products get more complex, the probability that errors occur increases (Oehmen, Dick, Lindemann, & Seering, 2006). In crises, engineers have to identify causes and develop technical solutions within short periods of time. Figure 1 (bottom) shows the general problem-solving approach following (Lindemann, 2009). In the lower box, two paths to compile technical solutions are illustrated: the direct path and the indirect path using abstraction. In crises, barriers, which inhibit problem solving, can occur in both paths. For instance, barriers in the abstract paths result from the lack of methods. As developers apply abstract problem solving to overcome crises, this paper aims to provide systematic methods to support their work. Because applying methods in product development increases the success of technical solutions (Graner, 2013).

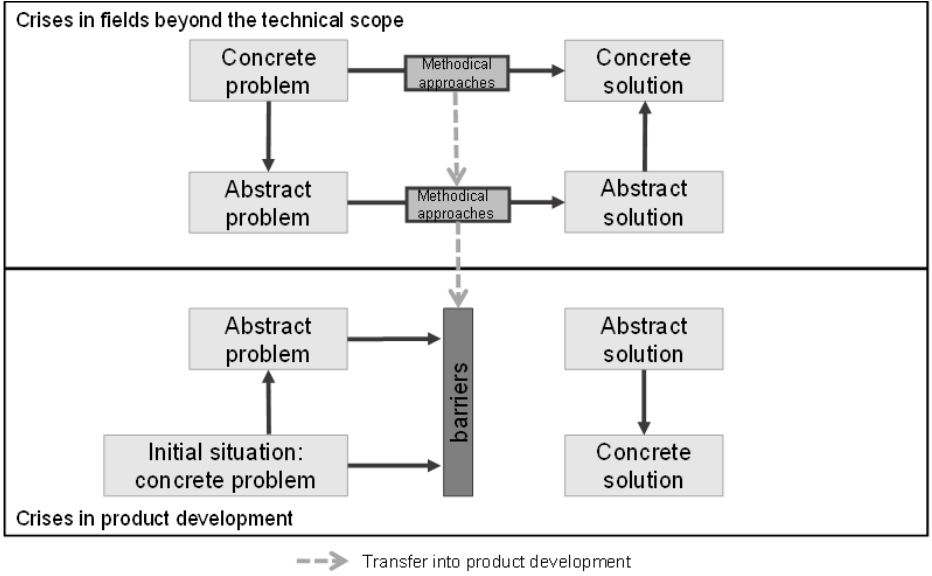

Figure 1: General crisis solving approaches and deficits in product development (following Lindemann 2009)

Initial research showed that both principal paths of problem solving also exist in fields beyond the technical scope. The goal of this paper is to identify successful approaches from crisis-proven organizations to cope with crises more effectively. Furthermore, these methodical approaches should be transferred into principles describing the application in the context of product development. Organizations beyond the technical scope, whose daily routine contains complex and challenging tasks, deliver input for elaborating the principles. Two organizations were chosen for research: the fire brigade Munich and an organization acting in the aviation sector. In order to reach the aim, the paper focuses on two research questions:

1. Which factors differentiate crises in other fields from crises in engineering product development?
2. Which methodical approaches can be identified in other fields and transferred into engineering product development?

The following Section 2 describes the research design of the studies. In Section 3, characteristics of crises are defined in the context of aviation and fire brigade. Section 4 introduces the elaborated principles. Section 5 contains the discussion of research results as well as a conclusion.

2 Research design

In order to define crises in fields beyond the technical scope and identify methodical approaches, two studies were run simultaneously. Focus was set on collecting qualitative data whereas literature did not serve as main source.

One study was conducted in cooperation with the fire brigade Munich. In discussions, routine as well as crises were defined. To understand decision-making processes, two workshops, which lasted three hours each, were conducted. During a simulation game, the participants answered a checklist. The simulation was videotaped. Besides the exercise, the participants filled a questionnaire concerning characteristics of crises and applied aids. In addition, practical exercises were observed focusing on communication. In the second study, characteristics of crises were discussed with employees of an organization acting in the aviation sector. To collect problem-solving approaches, two employees were questioned in guided expert interviews following King and Horrocks (2010). They were audio taped and documented in the form of event-driven process chains following Weske (2012). Following Weick and Sutcliffe (2001) these organizations were chosen since even under the most severe conditions they have comparable less accidents than other organizations.

After collecting qualitative data, the results were analyzed in order to identify relevant methodical approaches. These approaches were subsequently transferred into engineering product development.

3 Definition of crises in different fields

In different fields, individual characteristics of crises are defined. To clarify crisis definitions in the context of product development, fire brigade, and aviation, communalities and differences are determined. As a result, Figure 2 shows common characteristics based on the definition in product development. Beneath, further characteristics are listed according to the fields.

Fire officers added characteristics to the original definition. High dynamics and serious consequences of the decisions describe crises. In addition, fire fighters are not sure if measures taken will lead to success. A difference between crises in the context of product development and fire brigade is the duration of the situation. Crises in product development usually last longer than firefighting operations. The organization acting in the aviation sector emphasizes the non-controllability of crises whereas the time limit is negated. If all measures to cope with a situation fail and problems cannot be solved anytime soon, the situation will turn into a crisis. Main characteristics of the definitions coincide since high time pressure and deviations from aims characterize crises in all three fields. Therefore, methodical approaches can be transferred.

As no crisis could be identified in the organization acting in the aviation sector during researches, an exceptional situation served as basis for the interview study. An exceptional situation is comparable. The difference is that this situation is controllable.

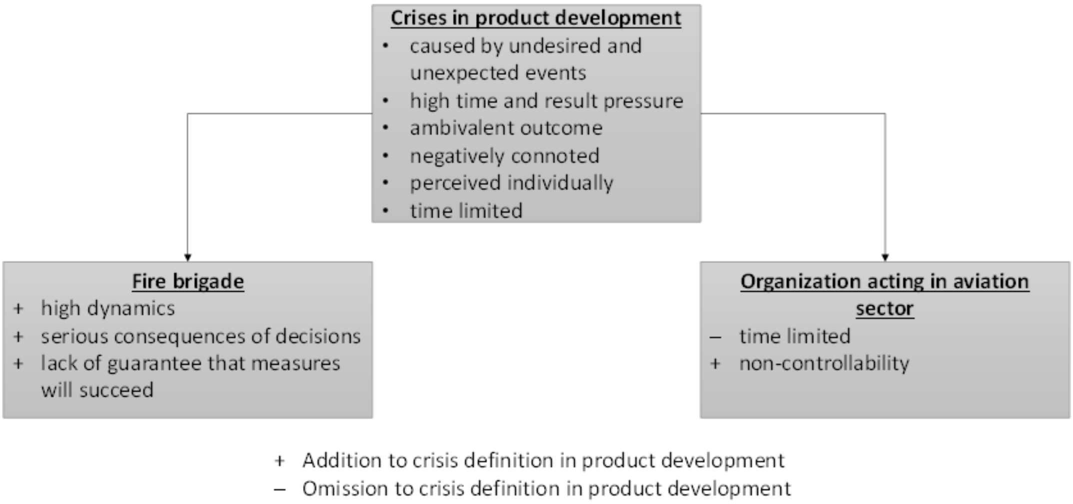

Figure 2: Communalities and differences of crisis definitions

4 14 principles to cope with crises

This section presents the research results. 14 principles to cope with crises in product development are introduced. Principles are defined as "proven […] tactical measures to manage procedures independently of concrete problems but relating to typical situations" (Lindemann, 2011). Main characteristics are summed up in the title of each principle.

Principle 1: Simultaneous causal research through teams of experts

The first principle contains two aspects: simultaneity of actions as well as employment of experts. Simultaneous work is advantageous as several engineers can accomplish tasks at the same time. Particularly in crises, when time is a scarce resource, simultaneous work can reduce the time to solve crises. In a technical context, simultaneous causal research is important because crises can only be solved when causes are clarified. But introducing simultaneous tasks may also increase communication effort within the crisis team since team members must circulate information and results. The second aspect of this principle is the involvement of experts. Experts have specific knowledge to conduct tasks successfully and quickly. If experts search for technical causes, crisis solving will be accelerated.

This principle originates from measures taken at the beginning of the exceptional situation. While initiating urgent measures to make employees' work possible, the responsible supervisor instructed technicians (experts) to search for technical causes.

Principle 2: Prioritization of tasks

This principle is composed of two aspects. The first aspect is the prioritization of crisis projects.

Crisis projects must be supported with all resources needed in order to stem negative effects. This aspect bases on the fact that the rescue of humans has always the highest priority in firefighting operations.

The second aspect is the elaboration of an order to manage tasks within the crisis project. By ranking tasks according to their relevance, available resources can be allocated to urgent tasks first. For that purpose, engineers should classify tasks in three categories: green, yellow and red. Tasks which are categorized red are urgent. As a consequence, resources needed must be provided with the highest priority. If a task is classified green, engineers consider it last. This categorization originates from a method to prioritize injuries. In case of many persons injured, paramedics decide which patients they treat first by determining categories. Weick and

Sutcliffe (2001) identified a similar ranking on command level. Operation teams were classified in bronze, silver and gold command levels. Further in product development, the classification can be combined with a system characterizing different states of work (in backlog, in progress, done) following (Ries, 2011, p. 138). Hence, engineers can quickly get an overview of all project tasks, their priority and their progress.

Principle 3: Distribution and delegation of tasks

This principle contains two aspects. The first aspect is the distribution of tasks. Within the crisis project, tasks should be distributed flexibly according to present persons. Assigning tasks at the beginning of the crisis project protects members from getting nervous or impatient, because they can immediately focus on their work. For that purpose, the team leader must clearly define tasks and roles. This aspect originates from distributing necessary tasks within the crisis committee due to the exceptional situation.

The second aspect of the principle is the delegation of tasks. In engineering product development, the team leader should delegate tasks after initiating first measures. Pursuant to the characteristics of the crisis situation, the leader has to decide which tasks he can refer to his colleagues. In the research study, the interviewees reported that the supervisor delegated tasks to his colleagues after taking urgent measures.

Principle 4: Early and ample resource request

Engineers should request supplementary resources as soon as possible in order to solve crises quickly. Once they decide that additional resources are necessary, they should insist courageously and confidently on their demand. Hence, crises allow that they try to request the best possible assistance. As crisis solving has the highest priority, all sorts of resources, which are likely to be needed, should be provided. Research results show that experienced fire fighters requested additional resources early and amply. For instance, one fire officer expected that more than ten persons are affected by a fire in an apartment house. He demanded additional vehicles and fire brigade units, although he did not know at this moment how many persons were actually inside the house.

Principle 5: Application of available resources

This principle sums up two aspects concerning resources: the request for additional resources and the four-eye-principle. In crises, all available resources should be gathered. The crisis team must select applicable resources in order to support crisis solving. If resources used in other projects are needed to cope with the crisis, they should be assigned to the crisis project. Hence, coping with crises has the highest priority within the company. Personnel, competences, machines and budget are regarded as resources (Garvin, 2000). In the research study, interviewees described that all available personnel was requested to arrive at the office. Afterwards, the supervisor selected necessary competences to cope with the exceptional situation.

The second aspect is the four-eye-principle. That means that one engineer checks his colleague’s work, e.g. design drawings. This concept aims to discover and correct mistakes. In crises, the additional effort is acceptable as new setbacks have to be avoided in any case. This aspect bases on the multiple-eye-concept to assist employees on duty applied during the exceptional situation in the context of aviation.

Principle 6: Establishment and preservation of a stable state

This principle consists of two aspects. The first aspect of this principle is the establishment of a stable state. In crises, employees’ and customers’ safety must be given top priority. On the one hand, the organization has to provide safe working conditions. For that purpose, equipment must work properly. Furthermore, engineers have to be enabled to focus on crisis solving by reducing their routine work. On the other hand, the organization must prevent customers from malfunctions of its products. This aspect bases on reducing workload initiated by the supervisor during the exceptional situation in the aviation sector, since safe processing could no longer be guaranteed to customers and employees.

The second aspect is the preservation of stable states. In engineering product development, tests and technical validations must be conducted to assure technical solutions. Thus, following setbacks can be avoided. This aspect of the principle originates from consecutive safety analysis to verify achieved states.

Principle 7: Clarification of time spans during working phase

This principle contains two aspects: the visualization and the estimation of time spans. The first aspect emphasizes the illustration of time. One team member should consistently visualize the current state of the crisis project. For that purpose, the employees can use time lines where they add deadlines and measures. This information should be illustrated in such a way that they are visible for every team member. Thus, in particular the team leader is able to check if measures taken succeed. As a consequence, he could develop alternative plans early if measures initiated fail. Furthermore, the leader can detect personal overloads and arrange necessary rest periods. This aspect is derived from two approaches: reporting time spans of five minutes to the responsible fire officer and visualizing chronological sequences on a magnetic board during the operation.

The second aspect of this principle is the estimation of time spans by experts. In product development, team members should estimate how long it will take to accomplish their tasks. Based on these realistic estimations, the team leader is able to plan his next steps more easily and prepare precautionary measures. This aspect originates from a methodical approach used by the rescue service to communicate time spans.

Principle 8: Establishment of spatial proximity or distance

This principle concerns spatial proximity as well as spatial distance. The first aspect states that the crisis team should be positioned in one office (“war room”). Thereby, engineers are able to communicate directly and quickly. As engineers’ concentration should not be disturbed, it is important that the team communicates information primarily during defined appointments. These meetings should take place in appropriate time spans. If team members are distributed all over the world, suitable communication channels will have to be defined. An improvement measure implemented after the exceptional situation served as basis for this aspect: The organization positioned two work areas next to each other to facilitate communication.

The second aspect is spatial distance. Engineers solving crises should work separately from coordinators. For that purpose, a specific office can be installed that also establishes distance to routine work. Engineers as well as coordinators can focus on their tasks: Coordinators aim to recognize the whole situation whereas engineers dedicate themselves to develop technical solutions.

Principle 9: Definition of communication structures and extent of exchange

The following principle consists of two aspects. By defining unique communication structures, engineers can transfer information quickly. Furthermore, only the persons who need the data are informed. This aspect originates from the unnecessary transfer of identical information between the office and the crisis committee.

The second aspect of this principle is the extent of exchange which must be determined. All members of the crisis team should assess collected data and only report relevant information.

As only important facts are communicated, the engineers do not have to waste resources by selecting information. Thus, they can save precious time. This aspect is extracted from a methodical approach to manage phone calls during the exceptional situation in the aviation sector. Since the responsible supervisor was not able to identify relevant calls, he delegated this task to his colleague.

Principle 10: Redundant use of communication channels

In general, redundant transfer of information increases the probability that the recipient detects the desired effect of the message (Ant, Nimmerfroh, & Reinhard, 2014). For this reason, engineers should use nonverbal communication and illustrations in crises. Preferring face-to-face communication, developers perceive nonverbal signals. If communication media is necessary, video transmission should be applied. Observations in exercises showed that fire officers used face-to-face communication with their units whenever it was possible. In order to emphasize their instructions, they used gestures.

In addition, engineers should employ graphical illustrations to visualize ideas and facts. Diagrams and drawings enable developers to understand correlations more quickly. Because drawings are the engineers' fundamental means of expression (Rutz, 1985). Research results demonstrate that fire officers' assistants visualize information on a magnet board during extensive operations.

Principle 11: Purposeful application of interrogative forms

Engineers should know advantages and disadvantages of open and closed questions to use them appropriately in crisis projects. Thereby, the efficiency of meetings can be increased. Open questions allow respondents to report all information they want. The team leader could use open questions if a team member has difficulties with his task. In that way, the member has the possibility to explain his worries. Observations demonstrate that fire fighters employ open questions when they arrive at a location and want to enable persons to describe the situation.

In contrast, respondents can answer to closed questions only with yes or no. In case of time pressure, the team leader should use closed questions to demand only the information needed. In that way, the crisis team do not waste precious time. Research results show that fire fighters pose closed question when time is scarce or the respondent is shocked.

Principle 12: Phrasing of work orders

Using a pattern to phrase work orders is advantageous because the team leader does not forget important components while issuing orders pressed for time. Furthermore, the team can employ the structure to document crisis solving consistently. Research results show that fire officers' instructions consist of five components: fire brigade unit, task, devices, aim and route. It is also possible that the officer only determines the unit and the task phrased as an aim. Based on this structure, the following pattern can be applied in engineering product development: team member(s), order, devices, aim and method. For instance, machines or computer programs are regarded as devices. Team leaders could also phrase their orders by specifying team members and the order as an aim. As a consequence, the group can make decisions autonomously. They can act more flexibly according to new information and events. The possibility to work autonomously can also motivate the team.

Principle 13: Prevention of personal overload

This principle concerns two aspects: the protection of work and information overload. The first aspect is related to the employees' workload in crisis situations. Engineers are not able to keep extremely high concentration for weeks as they suffer from physical and mental fatigue.

In order to prevent work overload, team leaders should evaluate team members' workload and initiate measures if necessary. For example, sufficient rest periods should be defined. If the team leader recognizes symptoms of fatigue, he will have to decide when replacements of project members are necessary. This aspect bases on different procedures to replace persons involved in crisis solving.

The second aspect is the prevention of information overload. In crises, decision makers should be protected from irrelevant information. For that purpose, colleagues should only transfer data directly referred to the crisis project. In this way, decision makers can concentrate on crisis solving and neglect personal and economic advantages. This aspect originates from the supervisor's decision making. Only after his replacement, he realized that his decisions also impacted customers and colleagues. He described that having this knowledge while acting, his decision making would have been negatively influenced.

Principle 14: Training for coping with crises

In order to cope with crises, engineers could draw analogies to the crises. Developers use their experiences to create analogies. Hence, it is important that they collect a lot of different experiences. Relevant sources are real experiences. These experiences will contribute to drawing analogies if developers identify problems and successes of measures taken. Therefore, engineers must reflect their experiences. To collect further experiences, crisis teams can conduct practices and simulation games. For that purpose, a game master prepares a crisis situation that the crisis team must solve within a few hours or days. It is necessary that the game master reacts flexibly to the team results in order to create a realistic situation.

Developers can use their collected experiences in the analogy model: At first, the crisis situation is divided into several segments. Afterwards, the engineer looks for analogies related to every segment. Therefore, known situations are compared to the crisis. If he can draw an analogy, he can transfer trends and measures into the current situation. In the course of a workshop, a participant compiled this analogy model to identify typical characteristics of an unknown situation. As sources the fire fighter named real experiences, experiences from exercises and simulation games, edited reports, mental simulations and colleagues' experiences. Klein (1999) also identified that fire officers used analogies within their decision making.

In order to structure the elaborated principles, four clusters are defined: *procedure, communication, human, training*. Table 1 shows all principles according to their cluster.

Table 1: Principle to cope with crises according to clusters

Cluster	Number of Principle	Title of Principle
Procedure	Principle 1	Simultaneous causal research through teams of experts
Procedure	Principle 2	Prioritization of tasks
Procedure	Principle 3	Distribution and delegation of tasks
Procedure	Principle 4	Early and ample resource request
Procedure	Principle 5	Application of available resources
Procedure/Human	Principle 6	Establishment and preservation of a stable state
Procedure/Communication	Principle 7	Clarification of time spans during working phase
Communication	Principle 8	Establishment of spatial proximity or distance
Communication	Principle 9	Definition of communication structures and extent of exchange
Communication	Principle 10	Redundant use of communication channels
Communication	Principle 11	Purposeful application of interrogative forms
Communication	Principle 12	Phrasing of work orders
Human	Principle 13	Prevention of personal overload
Training	Principle 14	Training for coping with crises

5 Discussion and conclusion

This paper aims to answer two research questions concerning crisis solving in engineering product development:

1. Which factors differentiate crises in other fields from crises in engineering product development?
2. Which methodical approaches can be identified in other fields and transferred into engineering product development?

To reply to the first research question, the definition of crises in engineering product development served as basis. The definition was compared with the understanding of crises in the firefighting and the aviation sector. Crisis understanding in the firefighting sector is similar to the understanding in product development. The definition was extended by the following aspects: high dynamics, serious consequences of decisions and the lack of guarantee that measures will be successful. The organization acting in the aviation sector did not agree the aspect that time is limited in crises. Further research is requested on the term *controllability* as understanding in product development differs.

The second research question was answered by analyzing and proceeding results from research studies conducted in both organizations. 14 principles to cope with crises in product development were elaborated. They are classified into the following clusters: communication, procedure, human, and training. These principles represent a holistic set of important instructions that support engineers in order to solve crises. Although some can be found in project management guidelines (e.g. Project Management Institute, 2013), the principles outreach this scope. Based on practical experiences, the elaborated principles enhance effective crisis solving. The principles contain general aspects to overcome crises in engineering product development. Since crises feature different characteristics, the application of the principles has to be adapted according to the individual situation.

In order to expand the elaborated set of principles, the concept of Crew Resource Management can be further analyzed. Initial researched showed that the concept was first used to train pilots (Flight Magazine, 2015). Gaba and Rall constituted a similar concept called Crisis Resource Management applied in emergency medicine (Rall & Gaba, 2009). For that reason, the concept of Crew Resource Management can provide supplementary insights into practical crisis solving.

This research shows the potential of analyzing and transferring crisis-solving approaches of organizations beyond the technical domain. Other organizations provide well-elaborated and crisis-proven approaches. Due to this knowledge transfer, engineering design methodology is extended and adapted to crisis-specific requirements.

Upcoming research studies should aim at the evaluation of the elaborated principles in engineering industrial practice. For that purpose, developers must apply the principles in practice. Afterwards, they must discuss challenges and successes of their application in order to improve the set of principles.

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Citations and References

Albers, A., Burkardt, N., Meboldt, M., & Saak, M. (2005). SPALTEN Problem Solving Methodology in the Product Development. In A. Samuel & W. Lewis (Eds.), *Proceedings ICED05, the 15th International Conference on Engineering Design.*

Ant, M., Nimmerfroh, M.-C., & Reinhard, C. (2014). *Effiziente Kommunikation: Theorie und Praxis am Beispiel "Die 12 Geschworenen"*. Wiesbaden: Springer Gabler.

Flight Magazine. (2015). Crew Resource Management: Human Factors for Pilots. Retrieved from http://www.crewresourcemanagement.net/introduction

Garvin, J. (2000). *A guide to the project management body of knowledge*. Newtown Square, Penn., USA: Project Management Institute.

Graner, M. (2013). *Der Einsatz von Methoden in Produktentwicklungsprojekten: Eine empirische Untersuchung der Rahmenbedingungen und Auswirkungen*. *Springer Gabler Research*. Wiesbaden: Springer Gabler.

King, N., & Horrocks, C. (2010). *Interviews in Qualitative Research*. London: SAGE Publications.

Klein, G. (1999). *Sources of power: How people make decisions* (2. ed.). Cambridge, Mass., London: MIT Press.

Krystek, U. (1981). *Krisenbewältigungs-Management und Unternehmungsplanung*. *Neue betriebswissenschaftliche Forschung: Vol. 17*. Wiesbaden: Gabler.

Krystek, U. (1987). *Unternehmungskrisen: Beschreibung, Vermeidung und Bewältigung überlebenskritischer Prozesse in Unternehmungen*. Wiesbaden: Gabler.

Lindemann, U. (2009). *Methodische Entwicklung technischer Produkte: Methoden flexibel und situationsgerecht anwenden* (3rd edition). Berlin: Springer.

Lindemann, U. (2011). *Methoden der Produktentwicklung: Methoden der Produktentwicklung Vorgehensmodelle - Grundprinzipien - Methoden,* Garching.

Oehmen, J., Dick, B., Lindemann, U., & Seering, W. (2006). Risk management in product developent - current methods. In D. Marjanovic (Ed.), *Proceedings DESIGN 2006, the 9th International Design Conference.*

Project Management Institute. (2013). *A guide to the project management body of knowledge (PMBOK guide)* (Fifth edition). Newtown Square, Pennsylvania: Project Management Institute, Inc.

Puttenat, D. (2009). *Praxishandbuch Krisenkommunikation: Von Ackermann bis Zumwinkel: PR-Störfälle und ihre Lektionen*. Wiesbaden: Gabler Verlag.

Rall, M. & Gaba, D. M. (2009). *Human performance and patient safety. Miller's Anesthesia,. Miller RD*: Philadelphia, PA: Elsevier, Churchill Livingstone.

Ries, E. (2011). *The lean startup: How constant innovation creates radically successful businesses*. London: Portfolio Penguin.

Rutz, A. (1985). *Konstruieren als gedanklicher Prozeß* (Dissertation). Technische Universität München, München.

Sonneck, G., Kapusta, N., Tomandl, G., & Voracek, M. (2012). *Krisenintervention und Suizidverhütung* (2nd edition). Wien: UTB.

Töpfer, A. (1999). *Plötzliche Unternehmenskrisen - Gefahr oder Chance?* Neuwied: Luchterhand.

Weick, K. E., & Sutcliffe, K. M. (2001). *Managing the unexpected: Assuring high performance in an age of complexity* (1st ed.). *University of Michigan Business School management series*. San Francisco: Jossey-Bass.

Weske, M. (2012). *Business process management: Concepts, languages, architectures* (2nd edition). *Computer science*. Berlin: Springer.