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IDENTIFYING PRODUCT DEVELOPMENT CRISES: THE POTENTIAL OF ADAPTIVE HEURISTICS

Muenzberg, Christopher (1); Stingl, Verena (2); Geraldi, Joana (2); Oehmen, Josef (2)
1: Technical University of Munich, Germany; 2: Technical University of Denmark, Denmark

Abstract

This paper introduces adaptive heuristics as a tool to identify crises in design projects and highlights potential applications of these heuristics as decision support tool for crisis identification. Crises may emerge slowly or suddenly, and often have ambiguous signals. Thus the identification of a project crisis is often difficult. Yet, to allow fast crisis response, timely identification is critical for successful crisis management. Adaptive heuristics are successful judgement strategies when limited and ambiguous information is available. This article presents a theoretical proposition for the application of heuristics in design sciences. The paper compares crises to 'business as usual', and presents sixteen indicators for emerging crises in product development. These indicators are suggested as cues for adaptive heuristics. Specifically three heuristics are found to be well suited to support design practitioners to make robust inferences about the situation: 1. One-single-cue, 2. Fast-and-Frugal-Trees, and 3. Tallying. The paper presents application scenarios for these three heuristics and provides an outlook on further research on adaptive heuristics in design sciences.

Keywords: Decision making, Project management, Uncertainty, Crisis, Adaptive heuristics

Contact:
Christopher Muenzberg
Technical University of Munich
Institute of Product Development
Germany
muenzberg@pe.mw.tum.de

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1 INTRODUCTION

In product development crises, fast decision-making is crucial for the success and survival of the project. This starts with the very first decision: Is the project in a crisis that needs immediate action, or can we continue with development as usual? This decision is of highest importance since it determines future immediate actions, i.e. whether standard problem-solving processes will be followed or whether the situation is escalated, and designers will manage the situation as a crisis. The timely judgement whether the project is in a crisis has impact on potential success and failure of the project. If crises remain unidentified, no immediate action is taken, thus the crisis tends to become more acute, potential mitigation actions dwindle, and subsequent costs and time increase for getting the project back on track. However, if every situation escalates to a crisis, the usual development activities are interrupted unnecessarily, and the team loses momentum as well as ability to react when a 'real' crisis emerges.

Deciding whether the project is in a crisis or not is challenging due to incomplete or ambiguous information, and a lack of time to gather more knowledge. There is a fine line between usual day-to-day changes and the early warning signs of a crisis or critical situation. The analysis of disciplines regularly facing crisis situations, e.g. civil and military aviation or emergency medicine, shows that situation awareness is an essential component for successful crisis management. Enhanced crisis identification skills contribute to improved situation awareness in projects. Thus the question arises: How can designers be a step ahead of the game, and quickly recognize the need for a more drastic intervention? In other words: How can designers reliably decide whether they are in a crises situation, under time pressure, and with lack of information?

Traditional decision support tools, like Multiple Criteria Decision Making, require reliable information, well-structured problems, and are time consuming. Thus they struggle in circumstances of emerging crises. However, 'adaptive heuristics', a class of decision strategies based on typical human cognitive shortcuts in reasoning, can strive in these challenging conditions (Gigerenzer and Gaissmaier, 2011). These decision strategies omit certain information and rely only on a small number of ‘cues’ and are thus 'fast and frugal' (Gigerenzer *et al.*, 1999).

In this paper we will argue how adaptive heuristics can help enhance situation awareness, and support the design practitioner to come to robust inferences about the situation. In particular, we will propose three adaptive heuristics design practitioners can apply to identify a crisis quickly.

The term 'heuristic' contains a broad array of different simplifying cognitive strategies and is only loosely defined. So far, design research has considered heuristics mostly as strategies or simple design rules to support the development process, but not for managerial decision-making. A keyword search for ‘heuristic*’ on the Design Society publication database[1], summarized in Table 1, resulted in 44 publications, of which 33 discussed design heuristics (e.g. Yilmaz *et al.*, 2010; Voss *et al.*, 2014; Sarnes *et al.*, 2015). Other articles presented heuristics for teaching (e.g. Hillen *et al.*, 2009), or biases introduced through the unconscious use of heuristics (e.g. Gräßler *et al.*, 2016). Only one publication, Keller *et al.*'s (2006) article on change prediction, applied the term heuristic for a strategy to judge situations and support decision-making. A keyword search on Scopus for 'design' and 'heuristic*', limited to publications relevant to engineering design, resulted in similar findings of heuristics being used as design rules, but not for managerial decision-making and situation judgement. This overview shows the broad use of the term heuristics, and the current neglect of heuristics as a decision-making tool.

Table 1. Results of keyword search for 'heuristic' in the Design Society publication database (in total 44 publications, some are counted in two categories)*

Heuristics as…	No of publications
design rule	33
tool for situation judgement	1
root of biases	5
other	9

1 https://www.designsociety.org/publications/5/papers

With this paper we introduce a new spin on heuristics as managerial decision support tool for design sciences. We focus on the concept of adaptive heuristics that are 'ecological rational', i.e. rational in the decision context they are applied. This concept from cognitive science and psychology has proven useful in other, similar applications, and is promising since "it is fast and frugal as it relies on "a minimum of time, knowledge, and computation to make adaptive choices" (Gigerenzer *et al.*, 1999, p. 14)" (Artinger *et al.*, 2015).

This paper will present a conceptual proposition at the intersection of research on adaptive heuristics, and design sciences. The presented argument follows a "Borrowing and Extending" approach (Zahra and Newey, 2009) by introducing the theory of adaptive heuristics to design sciences and thus sparking research in a new context that can inform back to research on adaptive heuristics.

In particular, we will present three heuristics from the ‘Adaptive Toolbox’, namely single-cue heuristics, lexicographic heuristics, and tallying strategies. We argue that these three heuristics can support design practitioners in crisis identification and increase their situation awareness. The paper has thus two goals:

1. Introduction of the concept of adaptive heuristics to design sciences.
2. Highlighting potential application of adaptive heuristics as decision support tool for crisis identification.

To achieve these goals the remainder of the paper is divided in three parts. First, we give an overview about crises in product development. We highlight the special characteristics of a crisis and potential indicators to identify an upcoming crisis. We provide an overview of adaptive heuristics. Based on this, we present in the second part generic heuristics for the identification of a crisis in a product development project. In the third part we discuss our conclusions by giving an outlook how to study and formalize the proposed heuristics in the industry context and highlight potential application of heuristics in other decision problems in product development.

With this paper we aim to contribute to research and industry alike. Regarding research in product development we introduce adaptive heuristics as decision-making strategies. Regarding industry we propose three heuristics which can help designers in making fast and frugal decisions. The application of these heuristics can support successful management of product development projects through company-specific adaptation.

2 THEORETICAL FOUNDATION

This section will introduce the key concepts of crises in product development, and adaptive heuristics. We thus provide the theoretical basis for subsequent theory building at the intersection of these two fields, which we will discuss in section 3.

2.1 Business as usual vs. crisis

Designers can be in different situations during the development of a product. In this paper we focus on one key distinction: *business as usual* (BaU) and *crisis*. Being aware of when the situation changes from BaU to crisis is important for the success of the project.

We define BaU as a situation in which a designer follows – consciously or unconsciously – standard procedures, e.g. Pahl and Beitz (2013) or Ulrich and Eppinger (2016). In this situation the designer knows what to do and the necessary actions to solve challenges or problems. In some way his actions are intuitive and do not need a lot of effort.

The term 'crisis' is widely used in many domains, e.g. in political sciences, business finance sciences, or psychology. Due to this wide use, no single definition dominates (Simola, 2005; Coombs, 2000). To narrow our research object and to give detailed descriptions, we build on the definition of crises in product development proposed by Münzberg *et al.* (2016). For the purpose of the paper we define a crisis in product development as:

A product development crisis is an exceptional situation during the development or usage phase of a product. Crises are described with the three elements: causes, processes, and effects.

Undesired, unexpected or unnoticed events cause a crisis. The situation has an individual impact on the team members, is limited in time, and has ambivalent outcome. It is associated with high time and result pressure. If a crisis is not solved it has serious impact on human life, environment or the company.

In this definition we acknowledge the limited research on crises in design sciences and build on the finding of business management and organizational crisis management, e.g. Burnett (1998), Coombs and Holladay (2011; Milburn) or Mitroff (1988). This research is closely connected to crises in the technical domain. Furthermore, they provide robust and tested models, crisis processes, and use cases which provide a good starting point for the characterisation of crises in product development.

Based on the models from business management and organizational crisis management, Münzberg et al., 2016 highlighted the gap of knowledge regarding characteristics of crises in product development in a previous publication. In their study, based on Gericke *et al.* (2013), and a combination of literature review and interviews, they identified nine factors which characterize crises in product development: (1) project risk, (2) priority, (3) pressure to succeed, (4) individual time pressure, (5) coordination and division of work, (6) type of project control, (7) management support, (8) degree of motivation/morale, project motive, motivation and (9) reward and recognition. These factors have different characteristics in a crisis compared to BaU. The different manifestations of these characteristics for project risk, priority, pressure to succeed, and individual time pressure are shown in Table 2.

Table 2. Comparison of business as usual and crisis

Factor	**Business as usual**	**Crisis**
Project risk	↓ →	↑
Priority	↓ →	↑
Pressure to succeed	→	↑
Individual time pressure	→	↑
Legend: ↓ = low, → = regular, ↑ = high		

The remaining five factors are more subtle in their differences between BaU and crisis. Projects in crises show special coordination and division of work, and different types of project control compared to BaU. Most notably, projects in crises often have special crisis management teams, so called firefighting or cheetah teams (Engwall and Svensson, 2004), which work decoupled from the daily business. These teams are supported by the top management to increase decision-making and availability of resources.

Additionally, motivation of the team members and project differs from BaU. Since major goals of the company or project are threatened, the involved persons usually have high interest (intrinsic motivation[2]) to solve the crisis. These personal stakes are connected to the typical prioritisation of crises in companies, and the special recognition and reward to those contributing to overcoming the crisis.

The causes of a crisis can be clustered in four categories: Origin, type of breakdown, time, and intention. Origins can be external events, i.e. events that arise outside the organization, or internal events, i.e. events that arise within the organization. The type of breakdown can be technical or economic problems, e. g. defects, accidents or system failure, or social and organizational events, e. g. sabotage, miscommunication or terrorism (Mitroff, 1988, p. 286ff.). Time-related analysis of crises in product development (Töpfer, 1999; Lindemann, 2009) show that causes can occur suddenly, e.g. food infected with Salmonella, or emerge in a creeping process, e.g. bad company strategies or decision traps during project work (van Oorschot *et al.*, 2013). Finally, crises can be clustered by the intention. A crisis can be triggered by intentional actions, i.e. sabotage or fraud, or unintentional actions, e.g. mistakes or misunderstandings (Coombs, 1995, p. 455).

Table 3. Overview of crisis indicators (Münzberg et al., 2015)

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

2 For this paper we do not cover the issue of political motivated interests or the deviation between personal and company goals. For an overview of opportunistic behaviour in project decisions see Stingl and Geraldi (2017).

Due to the severity of the expected effects, identifying a crisis and starting counteractions are of major importance inside an organization. Crises are the result of unexpected, unmitigated or unnoticed risks and are often hidden until the risks materialize. However, there are indicators which can show an emerging crisis. Münzberg et al. (2015) identified sixteen indicators for an emerging crisis (see Table 3).

Depending on the type of the cause and type of crisis development process (sudden occurrence vs. creeping process) these indicators have different meaning. Therefore, the relevance of these indicators is project-specific.

Risk management approaches support the early identification of potential causes of crises. Yet, not all potential crises can be identified and many are deliberately accepted and not mitigated. Moreover, if attempts of timely identification and mitigation of crises and their causes fail, the project enters a crisis and require crisis management (Geraldi *et al.*, 2010).

2.2 Adaptive heuristics

This section will introduce the concept of adaptive heuristics. The human mind constantly has to make judgement and decisions in an environment of uncertainty, ambiguity and lack of information. To cope with this complexity, we rely on cognitive shortcuts, called heuristics, which allow us to make sense of the chaos (Gigerenzer and Brighton, 2009). When using heuristics, we omit certain information and rely only on a small number of 'cues', i.e. relevant bits of information, to come to a decision or judgement. This may be as simple as relying on one single cue alone. Using heuristics thus reduces the cognitive load in decision situations and allows remaining decisive even in time pressured situations.

Research in cognitive sciences and psychology has kept a strong focus on the biases and errors that result when humans rely on heuristics in their decision-making – the departure point being Tversky and Kahneman's seminal work "Judgement under uncertainty: Heuristics and biases" (1974). Prominent examples of such biases are e.g. the 'recency heuristic', in which recent events receive a higher perceived importance than those longer ago (Hogarth and Einhorn, 1992), or the 'illusion of control', where individuals overestimate the probability of personal success (Langer, 1975). However, research around the German psychologist Gerd Gigerenzer, has, over the past decades, shown the usefulness of heuristics when applied smart and in the right environment (Gigerenzer and Gaissmaier, 2011). They introduced the concept of 'ecological rationality' and the 'adaptive toolbox'. Heuristics, as they claim, are neither good nor bad but a tool suitable for a specific problem and potentially useless for another (Pleskac and Hertwig, 2014). Gigerenzer et al.'s research program has revealed structural elements of adaptive heuristics, thus creating a classification of different heuristics and linking them with environments in which they can strive, i.e. where they are 'ecologically rational'. This structured view of heuristics enables to better understand expert reasoning, test expert judgment strategies for their usefulness and accuracy, and even to extract them as formalized decision support tools (Gigerenzer and Brighton, 2009).

The heuristics in the 'adaptive toolbox' share three elements that define them (Gigerenzer and Gaissmaier, 2011). These elements are, first, a search rule, which guides in which order information is collected, second, a stopping rule, which determines when to stop searching for additional information, and third, a decision rule which defines how to infer a decision or judgement from the information collected. In this article we will discuss three specific types of heuristic structures, which we found to be particularly useful to increase situation awareness and judge whether or not current situation constitute a crisis situation. First, **single-cue heuristics**: for this type the rules would take the simple form search for the single cue, stop when you collected information on the cue, and decide based on the value or quality of the cue. Second, the class of **lexicographic heuristics,** which follows a predefined or random sequence of cues for which information is gathered sequentially, and assesses after each step whether more information needs to be gathered or a decision can be made, e.g. because two alternatives differ significantly based in the cue. Third, **tallying strategies** that collect information on a predefined set of cues and conclude a decision based on parallel consideration of all these cues ('counting the "yes"').

An adaptive heuristic is ecologically rational given a certain decision environment, when it performs well in terms of predictive capabilities. Almost all real world judgements are bets, taking place in uncertain, possibly even random environments. Any strategy that supports decision-making is thus likely to fail in some instances. High predictive capability means consequently that the number of instances where the decision strategy leads to wrong inferences is low. Research on adaptive heuristics has thus evaluated the predictive capability of heuristics compared to other typical decision support tools, like multiple linear regression models, neural networks, decision trees, and others. In a series of studies, Gigerenzer et al. have demonstrated that adaptive heuristics can be just as good, or even better, in making predictions, than more complex models for specific decision and judgement problems (Goldstein and Gigerenzer, 2009). This effect was particularly pronounced for judgement situations, in which the learning sample was relatively small or the information environment highly ambiguous (Brighton and Gigerenzer, 2015).

More recent research has shown the usefulness of heuristics in real-world decision situations that require binary judgements based on unspecific, ambiguous information. Examples on where these heuristics have performed well come e.g. from emergency medicine, where a lexicographic approach provides robust estimates on the need for emergency care based on unspecific symptoms (Jenny *et al.*, 2015), or from military application, where again a lexicographic heuristic could reduce the number of civilian fatalities at military checkpoints due to wrong threat assessment (Keller and Katsikopoulos, 2016).

3 ADAPTIVE HEURISTICS FOR IDENTIFYING CRISIS SITUATIONS IN PRODUCT DESIGN

This section will bridge the two fields introduced in the last section and propose a theoretical concept at their intersection. We will subsequently show how crises indicators (Table 3) can be used as cues in three different types of heuristics to support the decision maker in distinguishing between BaU and crisis.

The judgement whether a design project is in a state of crisis is a tough call to make: Critical changes may creep in slowly, and signs that may indicate the crisis are often fuzzy or unspecific. While this is a difficult environment for traditional decision support tools like balanced scorecards (Kaplan and Norton, 1997), it is an environment in which adaptive heuristics can perform well. The judgement problem for the design practitioner shares several key characteristics of the examples from emergency medicine and military operations cited before, most importantly:

- incomplete information coupled with lack of time to collect additional information;
- unspecific cues or signals that may have different potential roots;
- cues and signals that are likely to be correlated;
- dominance of experience, rather than book knowledge, regarding development of individual judgment capabilities.

We thus argue that adaptive heuristics can be useful in the specific judgement case of crisis identification in design projects. Consequently, we make the following two propositions:

1. Adaptive heuristics are – potentially unconsciously – applied by experienced design practitioners when they have to judge whether they are in a crisis situation or not.
2. Useful adaptive heuristics can be made explicit and formalized to serve as decision support tools.

To research the validity of the two propositions, we need to understand two elements that will enable us to identify heuristics. First, the potential cues that inform the judgement process and are considered relevant by the experienced practitioner. Second, the types of heuristics that are likely to be ecologically rational in the given judgement situation.

Regarding the cues, we can build on the crisis indicators identified in Table 3. The indicators themselves are to a high degree unspecific to the individual design crisis, and may, taken alone, also be the result of more specific and better manageable root causes. However, they may together build a pattern that the experienced practitioner can identify as crisis that requires action. Identifying the cues that contribute with higher weight to the final judgement – which have the higher ‘cue validity’ – may not be possible. However, specific types of adaptive heuristics, like tallying, can accommodate for this challenge (Hogarth and Karelaia, 2006). Also, the majority of the indicators require qualitative judgement and are thus highly subjective. As such, they require a mode of consideration in the decision process that can accommodate for fuzzy signals, where the distinction between signal and noise is not clear cut. Again, adaptive heuristics, especially lexicographic approaches, are apt to deal with this challenge (Luan *et al.*, 2011).

For the second element that informs future research, we propose three types of adaptive heuristics of which we argue they may be useful for structuring the cues in a way that allows robust judgements: One-single-cue, Fast-and-Frugal Trees, and Tallying.

One-single-cue is the simplest heuristic, being informed by only one cue that has both high cue validity and little fuzziness. Research has shown that business practitioners rely strongly on simple rules that consider only one cue (e.g. simple rules for strategy decisions (Bingham and Eisenhardt, 2011), hiatus heuristic in marketing (Wübben and Wangenheim, 2008), or step price heuristic in retail (Artinger, 2012)). We can thus assume that design practitioners rely on similar simple rules for specific types of crises, e.g. when the cue is linked to a specific, non-acceptable issue like severe safety problems of the product. For a similar challenge, change prediction in product design, Keller *et al*. (2006) proposed three cues taken from graph theory measures that serve as single-cue heuristics with high predictive capability for the task. Examples of such One-single-cue heuristic might be technical failures covered in high profile media or a threat to user safety during product usage, e.g. Samsung Galaxy Note 7 crisis.

Fast-and-Frugal-Trees are a more complex approach for considering relevant cues. They are a type of lexicographic heuristic, in which cues are ordered according to their validity and considered sequentially until a decision can be made. As such, they present themselves as skimmed down versions of decision trees, with only two branches per node, one of the branches always being an exit. Figure 1 shows a potential, non-validated structure of a Fast-and-Frugal-Tree for crisis identification. These heuristics are useful, when the general ordering of the cues is known but the clarity of the signal for each of the individual cues is fuzzy.

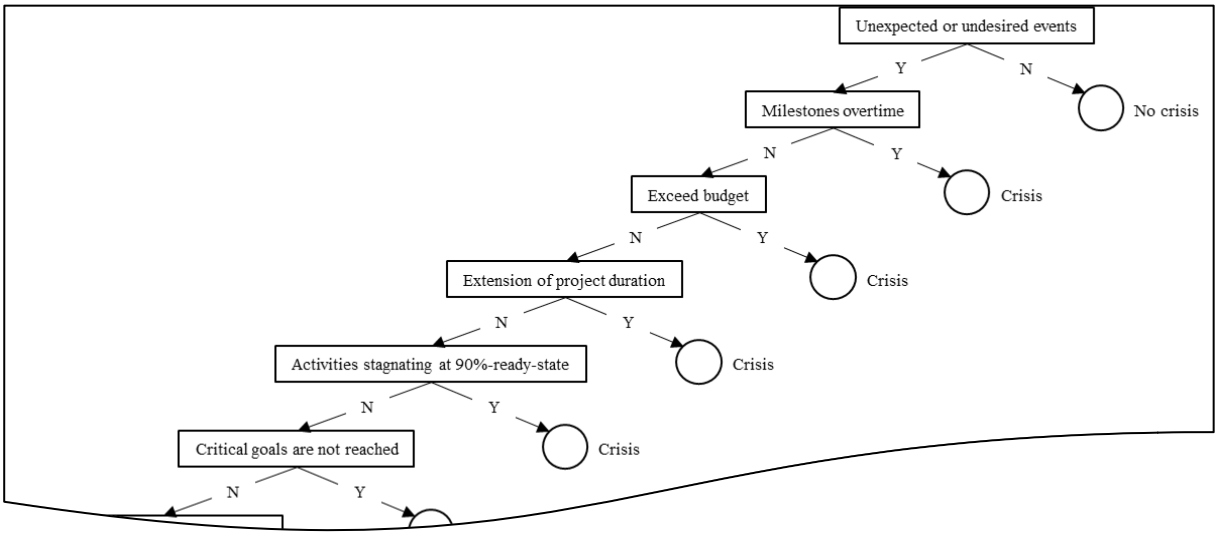

Figure 1. Example of a potential Fast-and-Frugal-Tree to identify crises based on crisis indicators

A Tallying approach is similar to Fast-and-Frugal-Trees, but instead of considering each cue independently, it considers all cues simultaneously and counts those that give indication for a crisis. The decision follows a predefined threshold of counts, above which the situation can be classified as crisis that requires action. This approach is suitable when there is no clear ordering in the importance of the individual cues, and furthermore when the signal of the cues is fuzzy. Figure 2 shows a potential structure of a Tallying checklist.

Indicator	**Yes(✓)/No(✗)?**
Milestones overtime	✓
Exceed budget	✗
Extension of project duration	✓
Activities stagnating at 90%-Ready-State	✗
Critical goals are not reached	

Figure 2. Exemplary checklist for a Tallying approach

Concluding, we made the following two claims. First, crisis indicators can serve as cues for heuristics for identifying crises. Second, One-single-cue, Fast-and-Frugal-Trees, and Tallying approach are useful heuristic types for crisis identification.
While literature in cognitive sciences and other application fields provide strong support for the second claim in particular, we currently lack evidence of their validity in the field of design crisis identification. However, following these claims and the proposition stated earlier, we may now formulate hypotheses that can be tested and validated through expert interviews or simulation experiments.

4 DISCUSSION AND OUTLOOK

In this paper, we have outlined a proof of concept that adaptive heuristics can support design practitioners in identifying product development crises. As we have shown in the theoretical foundations, crises are exceptional situations and far away from business as usual. Crises are dangerous for companies and projects success. Due to this, crises have to be detected as fast as possible by the project team. However, traditional decision-making tools may struggle due to ambiguous information and time pressure. A promising approach for such decision-making are adaptive heuristics. By focusing on a small number of cues and omitting information adaptive heuristics help decision-makers, e. g. project managers, to cope with complex situations. We introduced three heuristics, One-single-cue, Fast-and-Frugal-Trees, and Tallying approach, as possible tools to differentiate business as usual from crisis. Research in other disciplines, like emergency medicine or military operations, supports the claim that adaptive heuristics are useful strategies to assess situations in time pressured situations with limited and ambiguous information. However, the applicability and reliability of heuristics in product development and especially crisis identification has yet to be studied. For this, research needs to build upon expert knowledge to develop valuable heuristics for the application in industrial project work. For this reason we plan in our future research empirical studies, e.g. expert or group interviews and simulations, to verify the two hypothesis:

1. Adaptive heuristics are used by designers to identify potential crisis situations.
2. Formalized adaptive heuristics can support designers in identifying crisis situations.

In these studies we want to gather insight which implicit heuristics experienced practitioners use to make judgements and decisions. Furthermore, we want to explore the reliability of formalized heuristics for real-world judgement and decision problems in product development.
Further we want to highlight, that this paper focussed on designers in project work. However, we are convinced that the proposed decision-strategies are also useful for all project team members, e.g. engineers, constructors or project managers. Hence, the future empirical study should focus on these groups equally.
While we illustrated the potential for adaptive heuristics in crisis identification, we argue, that these heuristics can be useful for design decisions beyond situation judgements, e. g. crisis solution or engineering design problem solving. Some of the concepts developed in the research of adaptive heuristics have recently been picked up in aerospace engineering (e.g. Sarosh and Yun-Feng, 2016; Canellas *et al.*, 2015; Khan and Sarosh, 2013), and are worth exploring as design decision support in other fields of engineering design. Katsikopoulos (2012) overview of useful insights from psychology for design further shows the potential of adaptive heuristics in the field.
We thus believe that the introduction of the concept of adaptive heuristics to design science can spark insightful research, and provide useful contributions to the practice of design projects.

REFERENCES

Artinger, F. (2012), *Psychological mechanisms in strategic interaction under uncertainty*, Technische Universität Berlin.

Artinger, F., Petersen, M., Gigerenzer, G. and Weibler, J. (2015), “Heuristics as adaptive decision strategies in management”, *Journal of Organizational Behavior*, Vol. 36 No. S1, pp. 33–52.

Bingham, C.B. and Eisenhardt, K.M. (2011), “Rational heuristics. The ‘simple rules’ that strategists learn from process experience”, *Strategic Management Journal*, Vol. 32 No. 13, pp. 1437–1464.

Brighton, H. and Gigerenzer, G. (2015), “The bias bias”, *Journal of Business Research*, Vol. 68 No. 8, pp. 1772–1784.

Burnett, J.J. (1998), “A Strategic Approach To Managing Crises”, *Public Relations Review*, Vol. 24 No. 4, pp. 475–488.

Canellas, M.C., Feigh, K.M. and Chua, Z.K. (2015), “Accuracy and Effort of Decision-Making Strategies With Incomplete Information. Implications for Decision Support System Design”, *IEEE Transactions on Human-Machine Systems*, Vol. 45 No. 6, pp. 686–701.

Coombs, W.T. (1995), “Choosing the Right Words. The Development of Guidelines for the Selection of the "Appropriate" Crisis-Response Strategies”, *Management Communication Quarterly*, Vol. 8 No. 4, pp. 447–476.

Coombs, W.T. (2000), “Designing post-crisis messages: Lessons for crisis response strategies”, *Review of Business*, Vol. 21 No. 3/4, p. 37.

Coombs, W.T. and Holladay, S.J. (2011), *The handbook of crisis communication*, Vol. 22, John Wiley & Sons.

Geraldi, J.G., Lee-Kelley, L. and Kutsch, E. (2010), “The Titanic sunk, so what? Project manager response to unexpected events”, *International Journal of Project Management*, Vol. 28 No. 6, pp. 547–558.

Gericke, K., Meißner, M. and Paetzold, K. (2013), “Understanding the context of product development”, *ICED13 The 19th International Conference on Engineering Design*, Monday, 19 August 2013 - Thursday, 22 August 2013, Sungkyunkwan University, Seoul, Korea (South).

Gigerenzer, G. and Brighton, H. (2009), “Homo heuristicus: why biased minds make better inferences”, *Topics in cognitive science*, Vol. 1 No. 1, pp. 107–143.

Gigerenzer, G. and Gaissmaier, W. (2011), “Heuristic Decision Making”, *Annual review of psychology*, Vol. 62, pp. 451–482.

Gigerenzer, G., Todd, P.M. and ABC Research Group (Eds.) (1999), *Simple Heuristics That Make Us Smart, Evolution and cognition*, Oxford University Press, New York.

Goldstein, D.G. and Gigerenzer, G. (2009), “Fast and frugal forecasting”, *International Journal of Forecasting*, Vol. 25 No. 4, pp. 760–772.

Gräßler, I., Scholle, P. and others (2016), “*Enhancing Scenario Technique by Time-Variant Impacts*”.

Hillen, V.B., Banerjee, B. and others (2009), “*Modifying Design Pedagogy to Develop New Approaches to Sustainability*”.

Hogarth, R.M. and Einhorn, H.J. (1992), “Order effects in belief updating. The belief-adjustment model”, *Cognitive Psychology*, Vol. 24 No. 1, pp. 1–55.

Hogarth, R.M. and Karelaia, N. (2006), ““Take-the-Best” and Other Simple Strategies. Why and When they Work “Well” with Binary Cues”, *Theory and Decision*, Vol. 61 No. 3, pp. 205–249.

Jenny, M.A., Hertwig, R., Ackermann, S., Messmer, A.S., Karakoumis, J., Nickel, C.H. and Bingisser, R. (2015), “Are Mortality and Acute Morbidity in Patients Presenting With Nonspecific Complaints Predictable Using Routine Variables?”, *Academic emergency medicine official journal of the Society for Academic Emergency Medicine*, Vol. 22 No. 10, pp. 1155–1163.

Kaplan, R.S. and Norton, D.P. (1997), *Balanced Scorecard. Schäffer-Poeschel*, Stuttgart. DOI.

Katsikopoulos, K.V. (2012), “Decision Methods for Design. Insights from Psychology”, *Journal of Mechanical Design*, Vol. 134 No. 8, p. 84504.

Keller, N. and Katsikopoulos, K.V. (2016), “On the role of psychological heuristics in operational research; and a demonstration in military stability operations”, *European Journal of Operational Research*, Vol. 249 No. 3, pp. 1063–1073.

Keller, R., Eckert, C.M., Clarkson, P.J. and others (2006), “*Heuristics for change prediction*”.

Khan, A.A. and Sarosh, A. (2013), “Heuristic-intelligent design schemes a solution paradigm for transatmospheric cruiser”, *ICASE 2013: Proceedings of the Third International Conference on Aerospace Science & Engineering 21-23 August 2013, Islamabad, Pakistan, Islamabad, Pakistan*, IEEE, Piscataway, NJ, pp. 1–6.

Langer, E.J. (1975), “The illusion of control”, *Journal of Personality and Social Psychology*, Vol. 32 No. 2, pp. 311–328.

Lindemann, U. (2009), *Methodische Entwicklung technischer Produkte: Methoden flexibel und situationsgerecht anwenden, VDI-Buch*, 3rd ed., Springer, Berlin, Heidelberg.

Luan, S., Schooler, L.J. and Gigerenzer, G. (2011), “A signal-detection analysis of fast-and-frugal trees”, *Psychological Review*, Vol. 118 No. 2, p. 316.

Milburn, T.W. (1983), “Organizational Crisis. Part I. Definition and Conceptualization”, *Human Relations*, Vol. 36 No. 12, pp. 1141–1160.

Mitroff, I.I. (1988), “Crisis management: Cutting through the confusion”, *MIT Sloan Management Review*, Vol. 29 No. 2, p. 15.

Münzberg, C., Gericke, K., Oehmen, J. and Lindemann, U. (2016), “An Exploratory Study of Crises in Product Development”.

Münzberg, C., Venkataraman, S., Hertrich, N., Frühling, C. and Lindemann, U. (2015), “Crisis Situations in Engineering Product Development - A Method to Identify Crisis”, *ICED15 The 20th International Conference on Engineering Design*, Monday, 27 July 2015–Friday, 31 July 2015, Milan, Italy.

Pahl, G. and Beitz, W. (2013), *Engineering design: a systematic approach*, Springer Science & Business Media.

Pleskac, T.J. and Hertwig, R. (2014), “Ecologically rational choice and the structure of the environment”, *Journal of experimental psychology. General*, Vol. 143 No. 5, pp. 2000–2019.

Sarnes, J., Kloberdanz, H. and others (2015), "*Heuristic Guidelines in Ecodesign*".
Sarosh, A. and Yun-Feng, D. (2016), "The GA-ANN expert system for mass-model classification of TSTO surrogates", *Aerospace Science and Technology*, Vol. 48, pp. 146–157.
Simola, S.K. (2005), "Organizational crisis management. Overview and opportunities", *Consulting Psychology Journal: Practice and Research*, Vol. 57 No. 3, pp. 180–192.
Stingl, V. and Geraldi, J. (2017), "Errors, lies and misunderstandings. Systematic review on behavioural decision making in projects", *International Journal of Project Management*, Vol. 35 No. 2, pp. 121–135.
Töpfer, A. (1999), *Plötzliche Unternehmenskrisen – Gefahr oder Chance?: Grundlagen des Krisenmanagement, Praxisfälle, Grundsätze zur Krisenvorsorge*, Luchterhand, Neuwied, Kriftel.
Tversky, A. and Kahneman, D. (1974), "Judgment under uncertainty: heuristics and biases. Biases in judgments reveal some heuristics of thinking under uncertainty", *Science*, Vol. 185 No. 4157, pp. 1124–1131.
Ulrich, K.T. and Eppinger, S.D. (2016), *Product design and development,* Sixth edition, McGraw-Hill Education, New York, NY.
van Oorschot, K.E., Akkermans, H., Sengupta, K. and van Wassenhove, L.N. (2013), "Anatomy of a decision trap in complex new product development projects", *Academy of Management Journal*, Vol. 56 No. 1, pp. 285–307.
Voss, M., Sauer, T. and Bozkurt, H. (2014), "Using Design Heuristics in Idea Generation: Does it Take Expertise to Benefit?", *Proceedings of the 16th International Conference on Engineering and Product Design Education, University of Twente, Enschede, the Netherlands 4th - 5th September 2014*.
Wübben, M. and Wangenheim, F.v. (2008), "Instant Customer Base Analysis. Managerial Heuristics Often "Get It Right"", *Journal of Marketing*, Vol. 72 No. 3, pp. 82–93.
Yilmaz, S., Daly, S.R., Seifert, C., Gonzalez, R. and others (2010), "*Design heuristics in ideation across engineering and industrial design domains*".
Zahra, S.A. and Newey, L.R. (2009), "Maximizing the Impact of Organization Science: Theory-Building at the Intersection of Disciplines and/or Fields", *Journal of management studies*, Vol. 46 No. 6, pp. 1059–1075.