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Planning unplanned design iterations using risk management and learning strategies

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ABSTRACT

Unplanned design iterations are considered one of the reasons for the high failure rate of new product development (NPD) projects. Generally, organisations employ 'proactive risk management' (PRM) and 'reactive fast learning' (RFL) to manage unplanned design iterations. This paper aims to explore how organisations employ PRM and RFL approaches to manage unplanned design iterations in the NPD process. To that end, a cross-sectional interview study was conducted in eight organisations. The interview transcripts were analysed as a primary data source using thematic qualitative text analysis technique. For PRM approach, results demonstrate that the design teams were more active in risk monitoring in the design phase as compared to risk identification in the concept development phase. Generally, design teams reduced the likelihood of unplanned design iteration risks by employing learning methods in addition to risk mitigation strategies. For RFL approach, results reveal that organisations lacked a structured approach to select suitable learning methods for fast resolution of unplanned design iterations and to convert new knowledge into organisational learning. We conclude that PRM is more established as compared to RFL in managing unplanned design iterations. We develop recommendations of how organisations can use RFL approaches more efficiently alongside PRM approaches.

Introduction

The successful design and development of new products is an essential business endeavour in today's competitive business environment. To design, develop and launch new products in the market, companies use various procedures and methods categorised under new product development (NPD) (Ulrich and Eppinger 2016). In NPD processes, the aim is to minimise the development cost and time-to-market while improving the quality of products (Olechowski et al. 2012; Oehmen et al. 2010). However, the rate of NPD projects failing to meet the goals in terms of development cost and time, and reach the market is high. Barczak, Griffin, and Kahn (2009), for example, observed that approximately 40% of NPD

projects fail to enter the market. One reason why NPD projects encounter failure is due to the undesirable design iterations in the NPD process (Ballard 2000). As Ballard (2000) stated that informal surveys of design teams have revealed that design teams spent up to 50% of design time on needless or undesirable design iterations.

Design iterations comprise work containing correction, interdependency, or feedback (Unger and Eppinger 2002). However, explicitly, unplanned design iterations often arise in the form of rework when mistakes or feedback loops, unexpectedly, require a step backwards in the design phase (Unger and Eppinger 2009). By the very nature of NPD, design iterations are unavoidable and, in many cases, essential to create value in the design process (Krehmer, Meerkamm, and Wartzack 2009). However, the unplanned design iterations often cause delays and cost overrun in NPD projects as documented in the literature (Mujumdar and Uma Maheswari 2018; Eppinger, Nukala, and Whitney 1997; Krishnan, Eppinger, and Whitney 1997; Smith and Eppinger 1997; Smith and Tjandra 1998; Sobek et al. 1999; Costa and Sobek 2003; Jin and Chusilp 2006).

The existing body of research on 'design iterations' in NPD process generally has been restricted to the early detection of the potential design iterations, to avoid or plan the design iterations (Meier, Yassine, and Browning 2007). For example, to prevent or plan the design iterations, some studies refer to forecasts of design iterations using design structure matrices, modelling of the design process, buffering the design phase (Wynn, Eckert, and John Clarkson 2007), selecting suitable product development methods and using genetic algorithms (Meier, Yassine, and Browning 2007). These techniques address identification and sequencing 'planned design iterations' to optimise planning in NPD process. However, we contend that these techniques are poorly suited to managing unplanned design iterations because of their focus on predictable – and thus 'plannable' – design iterations only.

In an increasingly complex and uncertain product development context, unplanned design iterations are generally unavoidable (León, Farris, and Letens 2012) and have become a significant source of change risk propagation in the NPD process (Li et al. 2020). Therefore, instead of solely aiming to avoid unplanned design iterations, the aim should also be to manage unplanned design iterations in the NPD process and maximise the value each iteration generates for the overall design process (León, Farris, and Letens 2012). Hence, this paper focuses on making a contribution to managing unplanned design iterations in the NPD process.

Generally, design teams cannot predict which unplanned design iteration will occur when in the NPD process. However, to manage unplanned design iterations, design teams can probe potential triggers that cause unplanned design iterations. Triggers of unplanned design iterations include unclear requirements at the beginning of the NPD process, design complexity, technology uncertainty, errors or unforeseen design changes and update of new information (Eppinger 2001; Krehmer, Meerkamm, and Wartzack 2009; Mujumdar and Uma Maheswari 2018). As unplanned design iterations are, by their nature, based on the occurrence of unplanned rework, we conceptualise an unplanned iteration for the purpose of this paper as the occurrence of a specific class of product development project risk. With risk being defined as the impact of uncertainty on objectives (ISO 31000, 2018), unplanned design iterations are therefore considered a class of uncertain events that negatively impact an NPD project schedule. These risks can fall into two categories: Foreseen risks, i.e. foreseen possible, unplanned iterations identified as a risk during risk assessment,

but deemed not severe enough to warrant proactive mitigation actions during the planning process. And unforeseen risk, i.e. unforeseen iterations that were not identified during the risk management or other planning processes (Aven and Kristensen 2019).

Generally, two different approaches are practised to manage foreseen and unforeseen risk events that cause unplanned design iterations in the NPD process, 'proactive risk management' (PRM) and 'reactive fast learning' (RFL). The first approach is a 'proactive risk management' (PRM) approach, which identifies and assesses the (now foreseen) risks, at the start of the NPD projects, and subsequently implements a risk mitigation strategy to reduce the risk (either their likelihood of occurrence or significance of their impact) of unplanned design iterations (Unger and Eppinger 2011; Unger and Eppinger 2002). For example, at the beginning of NPD process, a PRM approach would identify the risks surrounding the clarity of design requirements and plan strategies for continuous and up-front requirements elicitation and validation to reduce the risk of costly unplanned design iterations in later stages of NPD process. However, literature studies reveal that a large proportion of design risks affect the performance of NPD process either before their identification, or after they were identified but not managed appropriately (Thamhain 2013; Beauregard 2015). In conclusion, the PRM approach reduces the number of unplanned design iterations by better identifying and subsequently proactively mitigating foreseen risks. There remains a significant potential to both better identify those risks, as well as developing improved mitigation actions to reduce the occurrence and impact of unplanned design iterations.

The second approach is 'reactive fast learning' (RFL), which primarily reduces the adverse impact of unplanned design iterations by building general organisational capabilities to deal with their occurrence more effectively. The RFL approach employs learning strategies to resolve unplanned design iterations faster, as well as generating greater progress from the iteration (and thus reducing the probability of subsequent iterations). The RFL approach uses learning strategies to increase technical and process related knowledge, which ultimately leads to faster resolution of unplanned design iterations. For example, an unforeseen introduction of new technology in a sub-system can cause an unplanned design iteration. It can be managed, as it emerges, by accelerated learning through fast testing of the technology and tools. In conclusion, the RFL approach reduces the adverse impact of unplanned design iterations by faster resolution using learning strategies.

An NPD process cannot completely prevent all unplanned design iterations. However, one possibility is to manage unplanned design iterations by reducing the 'number' of design iterations or reducing the 'impact' of unplanned design iterations on the progress of the NPD projects. We hypothesise that the combined utilisation of PRM and RFL approaches can better perform (than the present situation mentioned in the literature) in managing unplanned design iterations. The effective utilisation of both approaches can only be possible if design teams understand how and when these approaches are suitable to employ in their specific real-world scenarios. However, to our knowledge, there have been no empirical studies investigating when or how organisations use the PRM and RFL approaches, what types of foreseen and unforeseen risk events (which cause unplanned design iterations) are managed by each (or both) approaches, what kind of risk mitigation and learning strategies are used and how both approaches overall perform to manage undesirable unplanned design iterations in NPD process. The main aim of this paper, therefore, is to explore the utilisation of PRM and RFL, in a real-world scenario, by product development organisations in managing unplanned design iterations. To explore the practices of PRM and RFL

approaches in the product development organisations, we ask the following research question: *How do organisations employ both 'proactive risk management' approach, as well as 'reactive fast learning' approach, to manage unplanned design iterations in the NPD process*?

We aim to understand in which circumstances the two approaches, either separately or combined, are used and how they identify and mitigate the risk of unplanned design iterations. More specifically, the contributions of this paper are: (a) literature based study of existing NPD and engineering management literature and their mapping on PRM and RFL approaches (Section 3); (b) description and classification of triggers of unplanned design iteration risks observed in the empirical study (Section 4); (c) description of performance aspects of contemporary methods used in PRM and RFL approaches based on empirical observations of industrial practice (Section 5). This paper contributes, in broader terms, to the stream of work on the design research (Cash 2020) and more specifically of design methods and tools (Unger and Eppinger 2002; Unger and Eppinger 2011; Morkos, Shankar, and Summers 2012; Hsiao et al. 2016; Glover and Daniels 2017).

The remainder of the paper is organised as follows: Section 2 describes the research methodology used to collect and analyse empirical data from industrial practice. Section 3 lays out the literature-based results of the research, describing PRM and RFL approaches in the NPD process. Section 4 presents the results of the empirical study conducted in companies that demonstrate the description and classification of unplanned design iteration risks; practical use of PRM and RFL approaches in the NPD process. Section 5 discusses the implications of the results of the study. Section 6 finally concludes the discussion and suggests future work for the better utilisation of the PRM and RFL approaches in the NPD process.

Method

Research design

The empirical elements of our paper follow a deductive research approach (Bell, Bryman, and Harley 2018) as we attempted to empirically understand how organisations practice PRM and RFL to manage unplanned design iterations. The most suitable research method for the present work is employing the cross-sectional study (Bell, Bryman, and Harley 2018) as the nature of the study is exploratory. In the cross-sectional study approach, we selected semi-structured interviews as a primary data source to gain a detailed understanding of PRM and RFL used in NPD process. In semi-structured interviews, we endeavoured to achieve reliability and consistency by using an interview script that established the topics to be addressed (Shafqat et al. 2019b) during interviews.

Figure 1 illustrates a complete view of the research work divided into 6 phases. In the first phase, to answer the research question and facilitate the empirical study, we reviewed existing NPD and engineering management literature and mapped it on the two approaches, PRM and RLF. For the overview of the literature, we used Scopus and Science Direct databases. In searches, we focused on the titles, keywords and abstracts of the peer-reviewed papers. The following research strings were used with Boolean operators: ('product development process' AND 'design iterations'), (new AND 'product development' AND process OR projects AND 'design iterations' OR 'unplanned design iterations'), ('new product development' OR 'product development' AND 'risk management'), ('new product development' OR 'product development' AND 'risk management' AND 'design iterations' OR 'unplanned design iterations'), (New AND 'product development' AND method AND risk
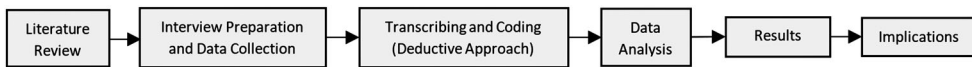
Figure 1. Outline of the research method.

AND management), ('new product development' OR 'product development' AND learning AND 'design iterations') and ('innovation' AND 'learning'). After the initial screening of the titles of the papers, the abstract, the introduction and the conclusion sections, we found 37 relevant research articles for the closer overview. We studied all chosen articles in detail and mapped the (21) most relevant literature in Section 3 (Proactive risk management (PRM) and reactive fast learning (RFL) – literature perspective).

In the second phase, by using literature review, we prepared the interview questionnaire and conducted interviews to collect data. We conducted 14 semi-structured interviews in 8 companies which were involved in NPD projects (explained in Subsection 'Data Collection'). In the third phase, we transcribed, read and got familiar with the data, which helped us to identify how and when PRM and RFL approaches were used in industrial practices. Then, we coded interview data using a deductive approach with the help of ATLAS.TI software (explained in Subection 'Data Analysis'). In the fifth phase, we complied results under emerging themes (PRM and RFL) from the deductive approach. Finally, we discussed the results and implications for managing unplanned design iterations in NPD process. The next two sub-sections (Data Collection and Data Analysis) describe the details of the 'Interview preparations and data collection', 'Transcribing and coding' and 'Data analysis' phases of the present research work.

Data collection

We conducted 14 interviews with CEOs, R&D directors, project managers and design engineers in eight selected companies which were all deeply involved in NPD projects. Table 1 presents an overview of the interviewee's job responsibility in each of the companies. We mainly conducted face-to-face interviews (11 participants) and held the remaining interviews (3 participants) over the phone. The interviews were conducted in eight Danish companies. The case companies were selected based on a set of criteria, including (1) companies with in-house product development, (2) physical products, (3) companies with ongoing NPD projects, and (4) headquartered in Denmark. We tried to avoid bias caused by cultural anomalies by focusing on the case companies in a single national context, i.e. Danish companies with in-house NPD projects. To ask for participation in the study, we contacted the interviewees via email, clearly explaining the purpose of the research.

During the course of the interviews, the interview script combined open and closed questions aiming to explore three topics (1) how PRM was performed in the NPD process (2) when and how PRM failed to mitigate (foreseen and unforeseen) risks of unplanned design iterations (3) how RFL approach helped or failed to reduce the impact of unplanned design iterations due to foreseen and unforeseen risks in NPD process (see appended list of open-ended interview questions). We used 'snowballing' (Bell, Bryman, and Harley 2018) as the sampling strategy during the interviews due to the exploratory nature of the study. We asked participants to provide as much detail as possible regarding their experience about managing unplanned design iterations using PRM and RFL approaches. We asked 'what if' questions to find out the participant's perceptions about managing unplanned

Table 1. Case company background, number of interviews and interviewee details.

Company ID	Industry	Major business region	Number of interviews at the company	Interviewee job area
Company A	Health Care	Global	5	A1: DE A2: DE A3: PM A4: PM A5: PM
Company B	Health Care	Global	1	B1: PM
Company C	Mining	Global	1	C1: PM
Company D	Health Care	Global	3	D1: DR&D D2: LE D3: RMg
Company E	Health Care	Global	1	E1: CEO
Company F	Oil & Gas	Nordic	1	F1: CEO
Company G	Oil & Gas	Global	1	G1: BRD
Company H	ICT	Global	1	H1: PM

Note: DE = Design engineer, PM = Project manager, DR = Director R&D, RMg = Risk manager, LE = Lead engineer, CEO = Chief executive officer, BRD = Business Risk Director.

design iterations by using risk management and learning methods. We recorded the interviews, lasting 45 and 60 min, on a digital audio recorder and transcribed using professional transcription service.

Data analysis

To examine the practices of using PRM and RFL approaches in managing unplanned design iterations and various types of foreseen and unforeseen risks, we used thematic qualitative text analysis technique (Kuckartz 2014). We analysed interview transcriptions as a primary data source. To address our research question, we coded each transcript multiple times and identified the relevant segments using ATLAS.TI software.

In the first step, to examine the participant's perceptions in the light of risk management and learning theories, we initiated data analysis primarily with a deductive research approach (Bell, Bryman, and Harley 2018). We developed literature review-based thematic categories (Kuckartz 2014), and coded interview transcripts using thematic categories as used by Field and Chan (2018). The codes included words, phrases or complete answers to the questions asked during the interviews (Saldaña 2015). For example, the thematic category 'risk assessment in NPD process' from the thematic area 'reducing unplanned design iterations using PRM' consists of all codes, including actions and tools, used to identify risks in the NPD process. We coded all the instances, which were providing relevant information; for example, events related to risk management (PRM) activities and learning activities (RFL) employed to manage unplanned design iterations (presented in Section 4).

In the next step, we analysed the codes from the previous step, with a theoretical lens from Section 3 (PRM and RFL – Literature Perspective), by inquiring whether the identified codes help us answer the research question. In the last phase, we categorised all the final codes under the thematic areas of 'reducing the unplanned design iterations using PRM' and 'reducing the impact of unplanned design iterations using RFL' in the NPD process. To answer the research question, the results from data analysis provided the basis to discuss (in 'Discussion' Section) both (PRM and RFL) approaches in the NPD context.

Proactive risk management (PRM) and reactive fast learning (RFL) – literature perspective

Proactive risk management approach in NPD processes

Fundamentals of risk management in NPD

Risk management is an essential part of NPD (Oehmen et al. 2010). Design teams commonly employ a risk management strategy to identify and manage risks in the NPD process. The well-accepted definition of risk covers positive (opportunity) and negative (threat) aspects of risk. The project management body of knowledge defines risk as 'an uncertain event or condition that, if it occurs, has a positive or negative impact on project objectives' (PMI 2008). However, in this paper, we discuss only identifying and managing negative aspect of risks that can cause undesirable, unplanned design iterations in NPD process. Therefore, we adopt the definition of risk from the ISO 31000 (2018) standard as risk being the effect of uncertainty on the NPD process's ability to meet its objectives. Uncertainties about critical events that may affect the performance of NPD projects are the causes of risks (Oehmen and Seering 2011). In a literature review, Oehmen et al. (2020) presented three fundamental sources of uncertainties which cause risks in NPD projects such as technology (e.g. risks arising from technology maturity), market (e.g. risks arising from changing customer expectations) and management (e.g. risks arising from organisation and processes).

In the context of the present paper, we define risk management as 'the process to uncover and manage risks in the NPD process, following a structured approach by initiating timely mitigation actions to avoid, transfer or reduce risk likelihood or impact' (AS/NZS 1999). According to the ISO 31000 (2018) standard, the core elements of the risk management process are as follows: establishing the context, risk assessment (including risk identification, risk analysis, and risk evaluation), risk treatment, monitoring and review, and communication and review.

Proactive risk management (PRM) and unplanned design iterations

Generally, NPD processes emphasise increasing the efficiency of the product design system. To minimise the number of unplanned design iterations, NPD process (usually) does not focus on reduction of uncertainty, even though it has the capability to reduce the uncertainty in a structured way (Oehmen and Seering 2011). Risk assessment, which is an integral part of the risk management process, plays a proactive role to identify, analyse and evaluate the risks that cause unplanned design iterations in the NPD process. Consequently, risk assessment in the NPD process enables companies to predict the potential risks and plan suitable actions for risk treatment (IEC 31010, 2009). Therefore, considering proactive approaches to manage risks that cause unplanned design iterations, traditional risk management can be associated with PRM approach in the NPD process. Employing a PRM approach to predict and evaluate the risks in the NPD process, design teams use different tools and techniques. The tools and techniques, which are typically used in risk assessment according to ISO/IEC standard (IEC 31010 2009), include, e.g. risk identification checklists, brainstorming, primary hazard analysis, hazard and operability studies, failure mode effect analysis, risk indices, bow tie analysis, fault tree analysis, cause and effect analysis, root-cause analysis, event tree analysis, fishbone tool, etc.

We hypothesise that a PRM approach is suitable for NPD projects having low uncertainty and less complexity, e.g. incremental innovation type projects. High uncertainty and complexity in the NPD projects are accompanied by lack of (structured) process and technical knowledge that are necessary to employ PRM methods successfully (Aven and Kristensen 2019) as mentioned above, radical innovation type projects. Therefore, to reduce the number of design iterations, NPD projects with low uncertainty levels can identify a significant number of risks and plan mitigation actions accordingly (Unger and Eppinger 2009). For example, NPD projects with incremental innovation have low process and technical uncertainty levels, as most of the tasks are known through 'similar' previous projects. Therefore, arguably, the design team is fundamentally in a position where it can identify relevant risks using process, experience and technical knowledge.

At the same time, the PRM approach becomes increasingly problematic in a highly uncertain project environment, as it becomes increasingly difficult to identify and control risks early enough in the project reliably; i.e. before a risk manifests in an unplanned design iteration. Naturally, radical innovation type NPD projects have a high degree of process and technical uncertainty, as for example, full requirements are not known a priori and novel technical knowledge may be required to develop the product. Consequently, it is most likely that significant risks may not be identified by design teams using PRM at the start of the NPD process. For instance, Thamhain (2013), argues that risk assessment phase generally fails to predict the majority of the risks in NPD process, and the unidentified risks affect the performance of the NPD process in later stages.

Reactive fast learning approach in the NPD processes

Fundamentals of learning in NPD

Learning activities enhance the capability of the design teams to address design challenges occurring in the design phase of NPD process (Shafqat et al. 2019a). Persidis and Duffy (1991) state that 'designers learn when they encounter knowledge which is sufficiently different from their present state of knowledge'. Persidis and Duffy (1991) describe that learning consists of three sub-processes, including acquisition, generation and modification. They further explain that the acquisition represents the process to receive new knowledge or information; the generation presents creating new from the general knowledge, and the modification describes the process of altering the general knowledge. In the context of our study, we consider that learning occurs when the design teams face design challenges and acquire new knowledge along with the process-related knowledge and technical knowledge; generate solutions to resolve unplanned design iterations by modifying the existing knowledge; and increase the process knowledge and technical knowledge at the individual, team and organisational levels.

There exist several studies, which examine learning in connection with product development projects (Persidis and Duffy 1991; Cooper 1993; Lynn, Morone, and Paulson 1996; Lynn, Akgün, and Keskin 2003; Akgün, Lynn, and Yılmaz 2006; Cui, Chan, and Calantone 2014; Erichsen, Pedersen, and Steinert 2016; Un and Rodríguez 2018). To further understand learning in the RFL approach, we consider single-loop and double-loop learning theories by Argyris and Schön (1997). Argyris and Schön (1997) define single-loop learning as a process of error detection and correction, which permits the organisation to follow its current

policies. To describe learning associated with the RFL approach in the context of single-loop learning, we take the example of addressing unplanned design iterations in the later stages of NPD process. To resolve unplanned design iterations, the design team acquires new knowledge and develops new (technical) solutions on the product level. In this process, the requirements of the NPD project remain the same, and the NPD project execution processes also remain unchanged. The design team successfully resolves the unplanned design iterations, which can be associated with single-loop learning.

Argyris and Schön (1997) define double-loop learning as a process which modifies the organisation's underlying policies and objectives in the error detection and correction process. To describe the RFL approach in the context of double-loop learning, we take the example of the improvements in the organisation's standard operating procedures related to NPD project management or problem-solving process as a result of new knowledge gained in resolving the unplanned design iterations (including improvements to the risk management process). Therefore, the new solutions to the problems not only improve the product itself but also contributes to the overall knowledge of the organisation, which can be used to other projects. For example, Technical Review Boards, such as those used after the explosion of a Concorde jet in 2000, illustrate double-loop learning at the level of an entire industry (Cusick, Cortes, and Rodrigues 2017).

Reactive fast learning (RFL) and unplanned design iterations

To deal with unplanned design iterations in the NPD process, in the RFL approach individuals, design teams and organisations learn about new solutions of unplanned design iterations. As mentioned above, in learning loops, design teams enhance process-related knowledge and technical knowledge by using different methods for knowledge acquisition, generation and modification, collectively labelled as 'learning methods'. In a literature review, Shafqat et al. (2019a) summarised learning methods used in the design phase to solve design problems in the perspective of RFL. They categorised the learning methods into formal and informal learning methods (Shafqat et al. 2019a; Dalmaz, Possamai, and Armstrong 2015). The formal learning methods include past product reviews (Lynn, Akgün, and Keskin 2003); outsourcing (Un and Rodríguez 2018); prototyping and experiments (Erichsen, Pedersen, and Steinert 2016); knowledge acquisition (Henshall, Campean, and Rutter 2017); and learning by doing (Cui, Chan, and Calantone 2014; Henshall, Campean, and Rutter 2017). The informal learning methods include learning from incidents (Drupsteen and Guldenmund 2014; Henshall, Campean, and Rutter 2017); product failure (Henshall, Campean, and Rutter 2017; Drupsteen and Guldenmund 2014); and learning from team-mates and mentors (Leifer and Steinert 2011).

In the RFL approach, to resolve the unplanned design iterations, the design team employs suitable learning methods and quickly learns about solutions. However, learning methods are not necessarily efficient solutions in terms of time and money (Shafqat et al. 2019a). They can be prohibitively expensive and reduce the efficiency of the NPD process by increasing the development cost and time to market. Therefore, arguably, RFL methods should only be employed if (a) PRM-based approach is inapplicable due to the level of uncertainty and complexity faced by the NPD project (Tegeltija, Kozine, and Geraldi 2016) and (b) the organisation has developed generic capabilities to execute RLF methods quickly and on short notice while maximising the amount of knowledge generated (Shafqat et al. 2019a).

In the next sections, we analyse the interview data regarding practices of risk management and learning methods; and the overall performance of the PRM and RFL approaches in managing unplanned design iterations.

Results of interview study

This section presents the results of an empirical study on the interviewee's perceptions of managing unplanned design iterations using PRM and RFL approaches. We divide it into two subsections which describe the results based on the thematic areas as described in the method section, including the thematic areas 'reducing unplanned design iterations using PRM' and 'reducing the impact of unplanned design iterations using RFL'.

Reducing unplanned design iterations using proactive risk management

In this section, we introduced an overview of how and when design teams employ risk management to identify and mitigate (foreseen) unplanned design iteration risks using the following four thematic categories (as shown in Figure 2): *risk assessment in NPD process; risk mitigation strategies in NPD process; risk monitoring in NPD process; triggers of unplanned design iterations in NPD process*.

Thematic Category 1.1: risk assessment in NPD process
Generally, almost all organisations employed a traditional risk identification process at the start of the projects for fulfilling the requirement to proceed to the next phases of the NPD process. We observed in the data analysis that some health care companies made risk assessment mandatory from concept selection until the product was in the market. For example, the CEO of health care company (E) stated that 'projects are required to perform risk analysis from their concept selection until the device is in the market' (E1-E). On the
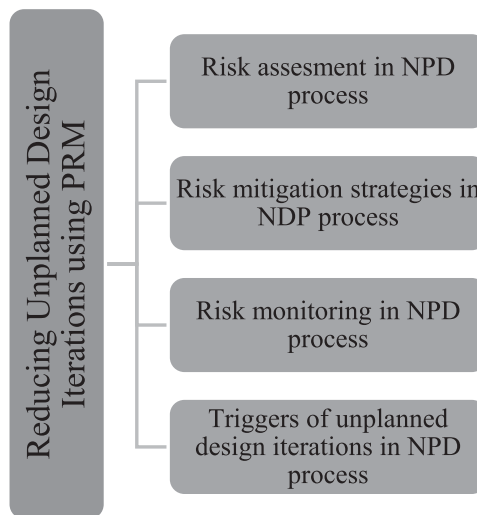
Figure 2. Thematic categories from thematic area 'reducing unplanned design iterations using PRM'.

other hand, an IT company (H) did not use risk assessment in a structured way to identify the risks. This may be exemplified by a project manager from the IT company who stated that 'we are not using risk management explicitly' (H1-H).

To identify risks of unplanned design iterations in NPD projects, the engineering design teams utilised risk management experts from the same health care organisation (D). A lead engineer stated that 'I don't do risk analysis as such, but I assess together with our risk manager' (D2-D). In some cases, the companies outsourced the risk assessment process; a project manager (C1) stated that 'in some cases, it (risk assessment) is outsourced' (C1-C). However, in the risk assessment process, the engineering design teams also expressed lack of confidence in external risk management experts. For example, a lead engineer (D2) expressed his concerns as

> (during) the risk assessment of the different functions (of product), if I don't sort of agreeing to them (external risk assessment) or believe in them […]. So, I start challenging those requirements, and the risk analysis, and then we have a dialogue (with external risk managers). (D2-D)

We observed that design teams most frequently employed HAZOP, FMEA and brainstorming for identifying and assessing the risks at the front-end of the NPD process. The companies did not use advanced computational methods to predict unplanned design iteration risks, for example, using 'Monte Carlo' simulations. A risk manager (D3) from health care company (D) stated that 'for project risks we use PowerPoint and Word […] and from the first concept, the first design, we will do iterations on HAZOP, and on FMEA' (D3-D). In some cases, however, the design teams did not get enough resources to perform risk analysis. A project manager (A5) stated that 'I would often say that the risk analysis didn't get the attention and the resources, and I think one of the reasons for this is that it's challenging' (A5-A).

The data analysis revealed that almost all identified foreseen risks belonged to technology and schedule-related risks. For example, a lead engineer (D2) from health care company (D) stated that 'I would say that we have struggled with […] the technical design risks […] with regards to usability, ensuring that it's easy for patients to use' (D2-D). Regarding schedule-related risks, a design engineer (A2) from another healthcare company (A) stated that 'we would always have risk concerning time to market' (A2-A).

Thematic Category 1.2: risk mitigation strategies in NPD process

Overall, we observed that along with employing various risk mitigation strategies, the engineering design teams also tried to reduce unplanned design iteration risks by deliberately planning design iterations in the design phase of the NPD process. In the planned design iterations, the design teams were mostly using prototyping, simulations and testing for mitigating technical risks. For example, a lead engineer (D2) from a health care company (D) stated that

> (after risk assessment) then it's my role to figure out, well, what's the most effective way forward. So, I can say do either simulation or some experimentation or this kind of things to mitigate the technical (unplanned design iteration) risks. (D2-D)

Another design engineer (A1) confirmed this by stating 'If we have more prototypes, then we have fewer risks' (A1-A).

In case of technical risks, failing fast was another option for the companies to choose alternative risk mitigation strategies. For example, a project manager (C1) stated that 'we do have some cases where it (engineering design) failed technologically […] that's an inherent part of the project, to get to that failure point as early as possible. And if you get to it, then you start over' (C1-C).

We observed in one NPD project that the design teams experienced re-occurring risks despite using risk mitigation strategies. For example, a project manager (C1) mentioned that 'we have a couple of risks that keep re-occurring […] and we are trying to mitigate them, but they are still re-occurring because they are hard to mitigate' (C1-C).

Thematic Category 1.3: risk monitoring in NPD process

To monitor unplanned design iteration risks in the design phase, almost all interviewees stated that continuous risk monitoring was an effective method. The design teams were more vigilant in risk identification in the design and development phase than in the conceptual phase or planning phase of the NPD process. For example, lead engineer D2 in health care company (D) stated that 'I use very active risk assessment (in the design phase) and I think it's become apparent also to others that it's a pretty effective way of working' (D2-D).

In almost all organisations, usually, project managers held weekly or biweekly informal meetings with design teams to update the list of technical risks. In these meetings, the design teams did not invite risk management experts to identify risks. For example, lead engineer (D2) stated that 'I do it (risk assessment) continuously, but once a week we have a tech meeting which I run, and the sort of the core in that meeting is our technical risk grid. So whatever challenges we have […] I put them all into this risk grid if it's not OK, and we use that for prioritisation' (D2-D). However, we also observed in a few NPD projects that there was lack of communication and ownership in design teams to monitor and report the risks to higher management. For example, a business risk director from company (G) stated that 'we try to have these meetings regularly and you create risk reports and so on. And basically, I have found it very, very difficult to make that work' (G1-G).

Some of the design engineers reported it is hard to perform risk monitoring, and their approach is more reactive than proactive. A project manager (A5) from company (A) expresses his opinion as 'in the project that I am now, we try to be proactive (in risk monitoring), but I think the main approach has been reactive for the many years' (A5-A).

Thematic Category 1.4: triggers of unplanned design iterations in NPD

We observed that the design teams did not consider several triggers of unplanned design iterations during the risk assessment and risk mitigation phases. During the interview study, several respondents mentioned triggers of unplanned design iterations including tight project schedule, changing product requirements, lack of communication between design teams, the bias of the people, lack of knowledge and experience in designing the product and complexity of the product under development.

For example, lead engineer (D2) stated that 'our biggest challenge is that the requirements are not well-defined from the customer side' (D2-D). Project manager (A4) confirmed this as he stated that 'I think some of the main problems are not being able to define the requirements in the early stages and continuously evolving requirements' (A4-A). When asked about triggers of unplanned design iterations, a project manager responded: 'I think from this project, it's primary communication if we don't communicate efficiently, […] then

we often do double work' (D2-D). We observed that in the development of medical devices, predominantly squeezed timelines were the main trigger of unplanned design iterations.

We observed in some of the NPD projects, additional triggers of unplanned design iterations including human error, willingness to take the risk, lack of ability to assess user needs, lack of continuous risk assessment in the later stages of the NPD process. For example, a project manager mentioned taking risk on purpose as a potential trigger to the unplanned design iterations. The project manager stated that

> we would say that we have a high risk of hitting this problem. We need this (action) to prevent it, and then they (higher management) were often willing to take that risk […] then we would hit it, and then the project would be delayed. (A5-A)

Another project manager (C1) expressed his concerns about the lack of ability to assess user needs. The project manager mentioned that 'for our part of development, our biggest challenge is getting a customer on board with testing (the equipment for assessing the user needs)' (C1-C).

In summary, the perceptions of reducing unplanned design iterations using PRM approach varied. We illustrated the content considered important in the current section ('Reducing Unplanned Design Iterations using PRM') and Table 2.

Reducing the impact of unplanned design iterations using reactive fast learning

In this section, we present a summary of results on how and when design teams employ learning strategies to reduce the impact of unplanned design iterations. It is divided into the following three thematic categories (as shown in Figure 3): *most frequent learning methods to resolve unplanned design iterations; learning from mistakes and failures in NPD process; most re-occurring unplanned design iterations in NPD process.* Together, these results provide insights into various aspects of using the 'RFL' approach, including the selection of learning methods, utilisation of learning methods and organisational learning.

Thematic Category 2.1: most frequent learning methods to resolve unplanned design iterations

To resolve unplanned design iterations, the interviews mentioned that the design teams employed various learning methods to acquire information and processing it to new knowledge. For example, the interviewees frequently referred to the use of prototyping, experimentation, testing, proof of concept, outsourcing and assistance from technical experts. However, in general, the companies lacked a proper selection criterion for the most suitable learning methods to resolve unplanned design iterations. A lead engineer stated that 'if we have three possible solutions to a problem, then we often just have to select one of them that we believe in, and sometimes pick the wrong choice' (D2-D).

We observed that prototyping was a commonly employed learning method to resolve unplanned design iterations. For instance, company (C), which was designing and manufacturing mining equipment, used prototyping in all phases of the NPD process. Another interviewee, when asked about prototyping said: 'we have several SLA (stereolithographic apparatus) machinery for building prototypes in very high quality. So, this is something that we have a high focus on it' (C1-C). In addition to prototyping, design teams also applied

Table 2. Summary of important results from 4 thematic categories.

Thematic category (Subsection)	Empirical results	Illustrative quotes	
Thematic Category 1: Risk assessment in NPD process	Generally, design teams employed risk assessment process with the help of risk management experts, and some design teams did not use risk management	'I don't do risk analysis as such, but I assess together with our risk manager' (D2-D)	'we are not using risk management explicitly' (H1-H)
	Design teams most frequently applied HAZOP, FMEA and brainstorming for identifying and assessing the risks. Some design teams did not get enough resources to perform risk analysis	'for project risks we use PowerPoint and Word […] and from the first concept, the first design, we will do iterations on HAZOP, and on FMEA' (D3-D)	'I would often say that the risk analysis didn't get the attention and the resources, and I think one of the reasons for this is that it's challenging.' (A5-A)
Thematic Category 2: Risk mitigation strategies in NPD process	The design teams mostly used learning methods, e.g. prototyping, simulations and testing for mitigating technical risks	'(after risk assessment) then it's my role to figure out, well, what's the most effective way forward. So, I can say do either simulation or some experimentation or this kind of things to mitigate the technical (unplanned design iteration) risks' (D2-D)	'If we have more prototypes, then we have fewer risks' (A1-A)
	In case of technical risks, failing fast was another option of the companies to choose alternative risk mitigation strategies. It was also observed in some NPD projects that the design teams experienced re-occurring risks despite using risk mitigation strategies	'we do have some cases where it (engineering design) failed technologically […] that's an inherent part of the project, to get to that failure point as early as possible. And if you get to it, then you start over' (C1-C)	'we have a couple of risks that keep re-occurring […] and we are trying to mitigate them, but they are still re-occurring because they are hard to mitigate' (C1-C)
Thematic Category 3: Risk monitoring in NPD process	Almost all design teams stated that continuous risk monitoring was an effective method and some design teams showed lack of communication and ownership to monitor and report risks to higher management	'I use very active risk assessment (in the design phase) and I think it's become apparent also to others that it's a pretty effective way of working' (D2-D)	'we try to have these (risk monitoring) meetings regularly and you create risk reports and so on. And basically, I have found it very, very difficult to make that work' (G1-G)
Thematic Category 4: Triggers of unplanned design iterations	Several respondents reported triggers of unplanned design iterations including tight project schedule, changing product requirements, lack of communication between design teams, the bias of the people, lack of knowledge and experience in designing the product and complexity of the product under development	'I think some of the main problems are not being able to define the requirements in the early stages and continuously evolving requirements' (A4-A)	'I think from this project, it's primary communication if we don't communicate efficiently, […] then we often do double work' (D2-D)
	Some respondents also reported additional triggers of unplanned design iterations including human error, willingness to take the risk, lack of ability to assess user needs, lack of continuous risk assessment in the later stages of the NPD process	'we would say that we have a high risk of hitting this problem. We need this (action) to prevent it, and then they (higher management) were often willing to take that risk […] then we would hit it, and then the project would be delayed' (A5-A)	'for our part of development, our biggest challenge is getting a customer on board with testing (the equipment for assessment of the user needs)' (C1-C)
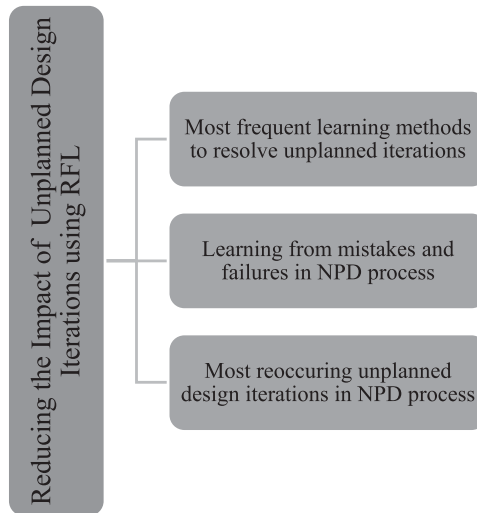
Figure 3. Thematic categories from thematic area 'reducing the impact of unplanned design iterations using RFL'.

testing and experimentation to resolve unplanned design iterations. For instance, a lead engineer (D2) stated that

> sometimes testing can be very cumbersome and even if we do calculations, they always contain assumptions. Sometimes we see that some of these assumptions don't hold true and then we just have to learn that we underestimated that one (assumption). (D2-D)

Thematic Category 2.2: learning from mistakes and failures in NPD process

Learning from failures and mistakes is the informal learning method to reduce unplanned design iterations in the next phases of the NPD process and future projects. The data analysis indicates that most of the companies lacked a structured process for converting knowledge from failures and mistakes into organisational learning. For example, a project manager (C1) stated that

> we have tried (to establish a process), but we don't have a consistent process for our lessons-learned, and it is something that is on the table. There is a framework to do that, but that framework is currently not running. (C1-C)

On the other hand, the health care company (D) used a special task force to secure the new knowledge and transfer it to other projects. As the R&D manager (D1) stated that

> we have tried to make databases on this (to secure knowledge), and it ends up in not being used. People are so busy with the projects, so they don't use all this stuff. What we instead do is that we try to circulate people between projects, bringing knowledge from one project to another. (D1-D)

Thematic Category 2.3: most frequent unplanned design iterations

Mostly, the focus of engineering design teams was on forecasting and mitigating the risks of unplanned design iterations. Generally, during the NPD projects, the engineering design

teams could not reduce the unplanned design iterations regarding changing requirements and complexity of the product. A project manager (B1) stated that

> I think some of the main reasons of the problems (unplanned design iterations) is that I am not able to define the requirements in the early stages (of NPD process). The requirements keep evolving the further you get in the process. (B1-B)

Regarding product complexity, R&D director (D1) of health care company (D) mentioned that 'we are facing challenges (unplanned design iterations), especially for those parts that are combination (complex) products. The products where you have the medicine integrated into the device' (D1-D).

The unplanned design iterations impacted the timeline and development cost of the NPD projects. We noticed that the cost overrun was not the critical impact of the unplanned design iterations in the health care companies. A risk manager (D3) from health care company (D) stated, 'I would say normally, the delay would be more important than the cost overrun' (D3-D). A project manager (A4) from another healthcare company stated: 'when we didn't manage to resolve (unplanned design iterations), […], everything delayed on the project, and often also delays in time to market' (A4-A).

In summary, the respondents expressed their various views about using learning methods to reduce 'the impact' of unplanned design iterations. We have presented important results in this section ('Reducing the impact of unplanned design iterations using RFL') and Table 3.

Discussion

To our knowledge, this is one of the few empirical studies that has been done to explore how organisations employ 'proactive risk management' (PRM), and 'reactive fast learning' (RFL) approaches for managing unplanned design iterations in NPD process. In this empirical study, we identified several insights that were consistent with past research. While utilising PRM, the engineering design teams maximised their focus on identifying and mitigating the unplanned design iterations risks traditionally in the conceptual phase and informally in the design phase of the NPD process (Wynn, Eckert, and John Clarkson 2007; Meier, Yassine, and Browning 2007); the design teams could not identify few unplanned design iteration risks (Thamhain 2013; Beauregard 2015); and the triggers of unplanned design iterations identified during the study were predominantly changing requirements, lack of knowledge and human errors (Eppinger 2001; Krehmer, Meerkamm, and Wartzack 2009; Mujumdar and Uma Maheswari 2018; Unger and Eppinger 2011). While employing RFL, the engineering design teams used various learning methods for fast resolution of unplanned design iterations (after their occurrence) specifically prototyping, experimentation and simulations (Shafqat et al. 2019a).

However, for many (but not all) study participants, several additional issues also influenced the practices of PRM and RFL in managing the unplanned design iterations. In particular, several study participants placed a high focus on using learning methods (along with other risk mitigation strategies) to mitigate unplanned design iteration risks prior to their occurrence; the engineering design teams were more active in risk monitoring in the design phase than in the concept development phase; mostly engineering design teams did not use many of the risk assessment tools which are recommended in ISO standards

Table 3. Summary of important results from 3 thematic categories with thematic area 'Reducing the impact of unplanned design iterations using RFL'.

Thematic category (Subsection)	Empirical results	Illustrative quotes	
Thematic Category 1: Most Frequent Learning Methods to Resolve Unplanned Design Iterations	The interviewees frequently referred to prototyping, experimentation, testing, proof of concept, outsourcing and assistance from technical experts. However, in general, the companies lacked a proper selection criterion for the most suitable learning methods to resolve unplanned design iterations	'we have several SLA (stereolithographic apparatus) machinery for building prototypes in very high quality. So, this is something that we have a high focus on it' (C1-C)	'if we have three possible solutions to a problem, then we often just have to select one of them that we believe in, and sometimes pick the wrong choice' (D2-D)
Thematic Category 2: Learning from Mistakes and Failures in NPD Process	The data analysis indicates that most companies lacked a structured process for converting knowledge from failures and mistakes into organisational learning. On the other hand, the health care company (D) used a special task force to secure the new knowledge and transfer it to other projects	'we have tried (to establish a process), but we don't have a consistent process for our lessons learned, and it is something that is on the table. There is a framework to do that, but that framework is currently not running' (C1-C)	'we have tried to make databases on this (to secure knowledge), and it ends up in not being used. People are so busy with the projects, so they don't use all this stuff. What we instead do is that we try to circulate people between projects, bringing knowledge from one project to another' (D1-D)
Thematic Category 3: Most Frequent Unplanned Design Iterations	Generally, during the NPD projects, the engineering design teams could not reduce the unplanned design iterations regarding changing requirements and complexity of the product. The unplanned design iterations impacted the timeline and development cost of the NPD projects	'I think some of the main reasons of the problems (unplanned design iterations) is that I am not able to define the requirements in the early stages (of NPD process). The requirements keep evolving the further you get in the process' (B1-B)	'when we didn't manage to resolve (unplanned design iterations), […], everything delayed on the project, and often also delays in time to market' (A4-A)

(IEC 31010 2009); some companies did not provide enough resources for risk assessment; organisations lacked a structured approach to select the most appropriate 'learning methods' for resolving unplanned design iterations after their occurrence; organisations lacked structured approach to capture new technical and process knowledge for the use of future projects.

Previous studies have emphasised on the early detection of potential design iterations in the conceptual phase of the NPD process (Wynn, Eckert, and John Clarkson 2007; Meier, Yassine, and Browning 2007). While using the PRM approach, we also found that engineering design teams were focusing on the prediction of unplanned design iteration risks. What our study adds to this view is the recognition of the need for 'active' risk monitoring in the detailed design phase to maximise the likelihood of predicting unplanned design iterations before their occurrence. For instance, for risk monitoring in the design phase, this study shows that the design teams held informal meetings and used brainstorming sessions to identify potential unplanned design iteration risks. They showed more ownership to risk monitoring in later stages as compared to the risk assessment phase at the start of the project.

In contrast to previous reports (Thamhain 2013; Beauregard 2015) indicating a limited capability of the risk assessment phase to identify many foreseeable risks, this study reports that the risk monitoring phase identified most of the foreseen unplanned design iteration risks which were missed in the risk assessment phase. For instance, to monitor unplanned design iteration risks, project managers held regular informal meetings with engineering design teams. Therefore, overall, the PRM approach performed better from an industrial perspective for identifying unplanned design iteration risks except for a few re-occurring risks in the design phase. One interpretation of this variation is that risk monitoring in later stages might be convenient for design teams due to the availability of more information and less uncertainty in the later stages of the NPD process. Such as, see, e.g. Oehmen and Seering (2011) reported that the NPD process does not focus on reducing uncertainty despite its capability.

Previous studies have reported the use of various risk mitigation strategies to reduce the likelihood of the occurrence of the risks (Hsiao et al. 2016; Abdul-Rahman, Mohd-Rahim, and Chen 2012). This study also indicates that various risk mitigation actions were used to reduce the occurrence of unplanned design iteration risks. However, this paper adds another dimension to risk mitigation actions by reporting the use of 'learning methods' as risk mitigation actions for reducing the likelihood of the occurrence of unplanned design iteration risks. For instance, the engineering design teams used prototyping and experimentation to reduce the likelihood of occurrence of the unplanned design iteration risks. This helped the design teams in reducing technical design uncertainty which ultimately led to the reduction of unplanned design iteration risks. The results also indicate that some of the unplanned iterations occurred despite the utilisation of risk mitigation strategies to reduce the unplanned design iterations. For instance, an R&D director stated that the projects in his company faced unplanned design iterations due to product complexity.

Unlike many other comparable studies, this paper did not focus on 'planned' design iterations. This enabled us to explore the approaches (PRM and RFL) for managing only unplanned design iterations both before and after their occurrence. The findings from this study indicate that the RFL approach is less established and structured as compared to the

well-established PRM approach for managing unplanned design iterations. For instance, the design teams employed learning strategies to resolve unplanned design iterations. Still, they were unable to select the most efficient learning methods for fast resolutions of the unplanned design iterations. For instance, a project manager had three (learning method) alternatives to resolve unplanned design iterations, but he selected (a learning method) alternatives based on his gut feeling. A possible explanation for this may be the lack of adequate experience of the design teams and lack of resources available to choose alternative learning methods.

The theory of single-loop learning and double-loop learning (Argyris and Schön 1997) highlights the importance of using learning and capturing new knowledge for the progress of future NPD projects. Apart from one organisation in the study, the findings from our study demonstrate that organisations, in general, lacked a structured approach to capture the new knowledge including process and technical knowledge while resolving the unplanned design iterations. Our study also reveals that companies were overall better in single-loop learning as compared to double-loop learning. For instance, a project manager (C1-C) mentioned that his organisation has the system to capture new knowledge, but it's not functional, and the organisation was unable to use the new knowledge in future projects. One possible interpretation of this might be the lack of motivation or incentives for the design teams to report new knowledge. They might consider this task as an extra burden and focus on their technical tasks only. This might also be the possibility that the organisations did not provide enough resources to establish a reporting system for new knowledge.

The findings from this study have significant implications for the organisations involved in NPD projects. The failure rate of NPD projects is very high (Barczak, Griffin, and Kahn 2009) and undesirable design iterations are one of the reasons for the failure of NPD projects (Ballard 2000). The management of unplanned design iterations (which are often undesirable) before and after their occurrence is an immensely important intervention for all organisations involved in NPD projects, but particularly with a high failure rate of the NPD projects. Design teams must manage unplanned design iterations efficiently. This includes minimising the likelihood of unplanned design iteration risks and fast resolution after their occurrence. Our study suggests that along with the prediction of unplanned design iterations, the fast resolution of unplanned design iterations using efficient learning methods is a crucial part of managing the unplanned design iterations. But the design teams may fail to manage unplanned design iterations (efficiently) after their occurrence without adopting a structured approach to select the most efficient learning methods.

Conclusion

Contribution

The purpose of the current paper was to close the significant gap in exploring the practices of 'proactive risk management' PRM and 'reactive fast learning' (RFL) for managing the unplanned design iterations by product development organisations. For this, we investigated the research question: How do organisations employ both PRM approach, as well as RFL approach, to manage unplanned design iterations in the NPD process? As an

answer, we presented empirical findings on how organisations manage unplanned design iterations using PRM and RFL approaches.

The most prominent finding to emerge from this empirical study is that PRM approach is well established as compared to RFL approach for managing unplanned design iterations. The research has also shown that, while employing PRM, the engineering design teams were more active for risk monitoring in design phase as compared to the concept development phase. For resolving the unplanned design iterations after their occurrence, the engineering design teams lacked a structured approach for selection of the most suitable learning methods. This finding suggests that, while employing RFL approach, it is essential to consider the most efficient learning methods (as already explained in theory and result sections) according to the categories of unplanned design iterations. One of the more significant findings to emerge from this study is that organisations failed to convert the new technical and process knowledge (gained during resolution of unplanned design iterations) into organisational learning. To avoid the unplanned design iteration in future NPD projects, this study suggests that it is vital to secure new knowledge and use it in future NPD projects through organisational learning.

Limitations

There are a number of limitations that affect the findings of this paper and should be considered for future research. First, the interview study was conducted in the organisations only headquartered in Denmark. The description of PRM and RFL practices to manage unplanned design iterations is likely affected by certain Danish cultural aspects. Therefore, this might limit the generalisability of the results in this paper. Second, we might have been affecting the interview study by our bias unwittingly, e.g. through questionnaire formulation, sample selection, or pushing specific aspects of the study during interviews. To avoid socially desired answers, we asked the same question in different ways. However, as in any interview study, the respondents might have given biased answers for unknown reasons. Finally, we conducted the interview study primarily in the engineering companies which might be extended to a broader context.

Future research

For future research, we have identified the two most significant findings from this paper as possible research topics. First, using the findings from this paper, future research should consider outlining a structure in the selection of the most efficient learning methods for resolving unplanned design iterations according to their specific category. Second, future research might consider studying why engineering design teams are more active in monitoring unplanned design iteration risks in the design phase than in the NPD process's concept development phase.

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Appendix. List of open-ended interview questions

The following questions give an idea about the type of questions asked during the interview study. Due to the study's exploratory nature, we used 'snowballing' (Bell, Bryman, and Harley 2018) as the sampling strategy during the interviews. Therefore, we started the interviews with the questions given below but did not stick to the questionnaire. We asked 'what if' questions to find out the participant's perceptions about managing unplanned design iterations by using 'proactive risk management' and 'reactive fast learning'.

1. Introduction
   - What is your role in the product development process (PDP)?
2. NPD Project Description
   - In which type of NPD projects are you involved in the company?
   - What is the (progress) status of the NPD project?
   - Which type of engineers (e.g. mechanical, mechatronics, electronics, software, etc.) are involved in the NPD process design phase?
3. Risk Management and Key Risks in Design Phase
   - Do you practice the traditional risk management process?
   - Do you employ risk management experts to identify risks?
   - Do you monitor design risks continuously?
   - What are the major risks (technical, market and organisational) and type of uncertainties in the design phase of NPD process?
   - Can you please give us an example of major risk, uncertainty, or design rework in the NPD process design phase?
   - How do you mitigate the design risks?
4. Unforeseen Risks in Design Phase
   - Can you please give us some examples of major design tasks in the design process that were particularly uncertain?
   - Can you please give us examples of unforeseen design risks that occurred during the PDP?
   - What are the causes of unforeseen design issues that caused design rework?
5. Learning Methods and Unexpected Design Challenges
   - How do you react to manage unexpected design challenges?
   - How do you learn about solutions to unexpected design challenges?
   - Do you get help from experts and learn from their experience for managing unexpected design challenges?
   - Were you prepared to manage unexpected design challenges?
   - Can you give us some examples of 'methods' used to solve unexpected design issues during the PD process?
   - What makes these 'methods' useful to you? What were the methods that were not useful, and why?
6. Learning from Failures and Mistakes
   - Do you learn from failures and mistakes in the design phase?
   - Do you have some organisational structure to capture new knowledge gained during the problem-solving process?
   - Do you learn from managing unexpected design iterations to manage design challenges in future projects?
7. Proactive Measures and Unexpected Design Challenges
   - If you could go back on time and meet yourself at the beginning of the design phase, what would you tell your younger self? Why?