A comparison of the integration of Risk management Principles in Product Development Approaches

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ABSTRACT
The management and reduction of risk is a central part of product development processes. This paper analyses the extent to which four common product development approaches address risks (waterfall model, spiral development, design for six sigma, and lean product development). They are analyzed along the four principles of risk-driven design: 1. Identifying and quantifying risks; 2. Making risk-based decisions; 3. Reducing risks; and 4. Creating resilient PD systems. The analysis shows that the existing PD processes only partially address the four principles of risk-driven design and that they have their specific strengths and weaknesses. The paper concludes with a discussion of preliminary empirical findings through interviews and case studies on how to better integrate risk management principles into product development.

Keywords: Risk management, product development process

1 INTRODUCTION TO RISK MANAGEMENT IN PRODUCT DEVELOPMENT

Risk management is an important element of product design. We adopt the ISO 31000 definition of risk as the "effect of uncertainty on objectives" [1]. If we think of the objectives of product development (PD) projects as developing products that meet or exceed stakeholders' expectations within budget and in a timely fashion, then any uncertainties that may cause delays, cost overruns, degradation in performance and/or misinterpreting stakeholder requirements are risks that need to be managed.

We argue that product development organizations are hindered by the many uncertainties and resulting risks that are inherent in the process. The US Department of Defense is currently confronted with a cost overrun in development and acquisition projects of close to $300 billion, and insufficient risk management is cited as one of the main underlying reasons [2]. In this paper, we therefore explore how four common product development approaches (waterfall model, spiral development, design for six sigma and lean product development) manage risks during product development. The objective is to discuss their specific strengths and weaknesses regarding risk management, in order to create the bases for an organization to choose the appropriate process and customize it to match its risk exposure.

2 LITERATURE REVIEW AND CONTEXT

2.1 Intrinsic and external risk management processes in product development

Risk management can either be treated as a separate process to the product development process [1, 3-5], or as an emergent property of the development approach itself [6, 7].

Dedicated risk management processes are structured in several phases, such as risk identification, risk analysis, risk evaluation, risk treatment and monitoring & review [1, 4, 5]. In this structure, the input / output relationship of the different process steps is described, as well as alternative methods to execute this process step. A review of the literature on risk management in product development [3] has shown that a number of methods exist to identify, quantify and monitor risks, but there are shortcomings regarding risk treatment (i.e. mitigation), as well as the overall integration of the risk management process with the product development process.

Analyzing risk management as an intrinsic part of PD approaches takes a different view. [6] for example discuss the dimensions of 'iterations' (from narrow iterations within a phase to comprehensive, cross-phase iterations) and 'review' (from rigid reviews that are frequent with fixed requirements to less frequent flexible reviews with soft requirements) to contrast waterfall, spiral and hybrid PD approaches in terms of their management of risks. Instead of prescribing a specific process on how to manage risks, [7] introduces 'four risk-driven design principles' that are solution-neutral and represent objectives or outcomes of successful risk management. These principles are: 1. Creating transparency regarding design risks; 2. Making risk-based decisions; 3. Minimizing uncertainty in design; and 4. Creating resilient PD systems.

2.2 Understanding of risk management for the purpose of this paper

The purpose of this paper is to analyze how different PD approaches manage risks, not to compare different risk management processes as such. It therefore follows [7] to understand how risks are managed in the different PD approaches by comparing how and to what degree certain principles of risk-driven design are addressed.

Principle 1 (creating transparency regarding design risks) addresses both exploring and identifying the uncertainties of the design process, as well as quantifying the related impact on objectives, i.e. risks.

Principle 2 (making risk-based decisions) addresses the way that insights regarding the risk exposure of the development project are integrated into decision making. Examples include: basing go/no go decisions for the development project at the overall risk or probability of success; allocating (scarce) resources to reduce and possibly eliminate the largest risks as early as possible; setting objectives that are associated with a risk assessment (i.e. probability of success), to enable transparent trade-offs; and entrepreneurial decision-making through risk-return assessments, e.g. high-risk options must promise accordingly high returns.

Principle 3 (minimizing uncertainty in design) addresses the different types of root causes for uncertainties that impact the objectives of the design project. If we assume that meeting or exceeding the stakeholder requirements regarding time, cost and performance are the main objectives, the root causes for uncertainties can be described in the following categories: company internal uncertainty, i.e. uncertainty regarding the efficiency and effectiveness of design processes and their execution, including skill levels and productivity of the workforce; supplier-related uncertainty, i.e. uncertainty regarding time, cost or quality of service or component deliveries; customer-related uncertainty, both regarding the stability of the customer requirements, as well as their clarity (i.e. quality of understanding of the requirements by the organization); market and macroeconomic uncertainty, such as political, social, environmental or economic developments; and technology uncertainty, both regarding cost, performance and availability of single components, as well as system integrations.

Principle 4, Creating resilience in the design system, addresses the ability of the design process to cope with the residual risks. It includes the two categories: The responsiveness of the design system describes how it reacts to unforeseen events, e.g. the ability to detect and correct errors quickly, cost efficient change management, or a flexible and versatile workforce. The second category addresses establishing critical and risk-appropriate buffers to accommodate negative impacts, regarding cost (financial reserves), time (schedule reserves), performance (redundancy or overengineering), but also lower-level buffers such as excess capacity of other resources (e.g. manpower or testing facilities).

2.3 Product development approaches

This paper uses 'product development approaches' as an umbrella term for product development processes and product development principles. Product development processes (PDP) are defined as the sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product [8]. Due to the dynamic nature of the market and the resulting challenges in the development of new products, the literature provides many different PDPs. In this paper, we investigate four common approaches to product development in more detail regarding their risk management approach: waterfall, spiral, Design for Six Sigma (DfSS) and lean product development. DfSS and Lean PD can be considered supportive principles of prescriptive PDPs such as the waterfall or spiral development processes.

The traditional waterfall model, also called stage-gate, phase-gate or life cycle by various authors, is one of the most widely used types of PDP and has been dominant in US industry for almost 30 years [9-11]. It is categorized as a sequenced process model [12, 13] and follows a linear progression of product development steps [14] (also see Figure 1). Every step or phase is rigorously reviewed at a stage-gate or milestone that determines whether the product development process can advance to the next phase. Otherwise it has to iterate within the current phase until all performance requirements are achieved [15, 16]. The main advantages of the staged process are that it imposes structure on development by reaching sharp product definitions and specifications early in Product Development, without necessarily demanding specific processes on how to reach the desired state. However, the main disadvantage arises from the difficulty of fully specifying product and customer requirements at the beginning of the project, especially in a highly dynamic market [6, 15].

The spiral model is a PDP that has found particular application in the software industry [6, 15, 17, 18]. It recognizes the repetitive nature and stepwise refinement in Product Development. It provides a risk-reduction approach by planning a series of iterations that span several phases of product development [6] (see Figure 1). The basic concept of the spiral model is to start on a small project scale, explore risks, develop a plan to handle the risks and commit to an approach for the next cross-phase iteration [15]. It therefore helps to screen and evaluate risks early, before major costs are incurred [17]. Each cycle considers the main spiral elements: critical stakeholder objectives, product and process alternatives, risk identification and resolution, stakeholder review and stakeholder commitment [17, 18]. As a project spirals outwards, each loop brings it closer to completion, while each movement away from the center reflects additional costs [9]. The main advantages of the PDP are the continuous stakeholder feedback throughout the project and the reduction of burdensome and expensive rework [6, 14]. The spiral PDP is appropriate for a complex project where customer and performance requirements are poorly understood. Several authors argue that high complexity and the significant required management attention are main disadvantages of the spiral model [6, 14, 15]. Boehm & Bose furthermore acknowledged difficulties in the first spiral step of determining objectives, alternatives and constraints due to the lack of explicit process guidance [19].

Design for Six Sigma (DfSS) is a structured method that aims at developing products to meet ‘six sigma’ expectations and customer requirements [20]. It provides tools and methods to proactively manage Product Development risks: Preliminary steps include comprehensive analysis, assessment and prioritization of risks associated with the business case and the project schedule [20, 21]. There are several possible alternatives for structuring the overall DFSS, for example RADIOV (Requirements, Architecture, Design, Optimize, Integrate, Verify) [21]. However, in executing the process, all process structures rely on the same (or very similar) set of methods e.g. Monte Carlo Simulations, DFMEA or QFD. This paper is focusing on the sequenced RADIOV approach by Maass & McNair [21] in order to analyze and discuss it regarding the applicability of the four risk-driven design principles. Figure 2 provides an overview of the structured method for DfSS in form of a flowchart.

Lean operation practices have achieved a great deal of success in both manufacturing industry and many service industries, such as banking, insurance, and health care [20]. This paper addresses Lean Product Development (Lean PD) according to the comprehensive investigations of the Toyota Product Development System by different authors [22, 23]. The lean PD practices include strong project manager, set-based engineering, process standardization, specialist career path, product variety management, workload leveling, supplier integration, responsibility-based planning and control, cross-project knowledge transfer, rapid prototyping, simulation and testing and simultaneous engineering [24].

2.4 Contributions of this paper

In summary, recent literature sources recognize PDPs as risk management structures, but do not compare different PDPs to each other [6]. Some authors use comparative empirical studies to suggest a method of comparing and/or matching PDPs and context [15, 25, 26], but do not focus on risk management. No sources could be identified to compare different PDPs in their approach to managing risk and uncertainty in the design processes: This paper addresses this literature gap and contributes a structured analysis and comparison of the risk management approaches of four different PDPs that is guided by the principles of Risk-driven Design.

3 COMPARISON OF RISK MANAGEMENT APPROACHES

3.1 The Traditional Waterfall Model

The waterfall model, with its sequenced stages, mainly focuses on reducing uncertainties in system integration and customer requirements with comprehensive up-front planning. The product functionality and performance is agreed prior to the start of the project and specifications [10]. Narrow iterations within, and rigorous quality reviews after each phase make sure to meet actual performance requirements, i.e. manage technical risks. Every gate consists of a set of checklist deliverables against which the project is judged [10]. Uncertainty regarding how the project team understands customer requirements is reduced with extensive market screens and evaluations at the beginning of the process e.g. review of opportunity and market attractiveness, product advantages or strategic alignments.

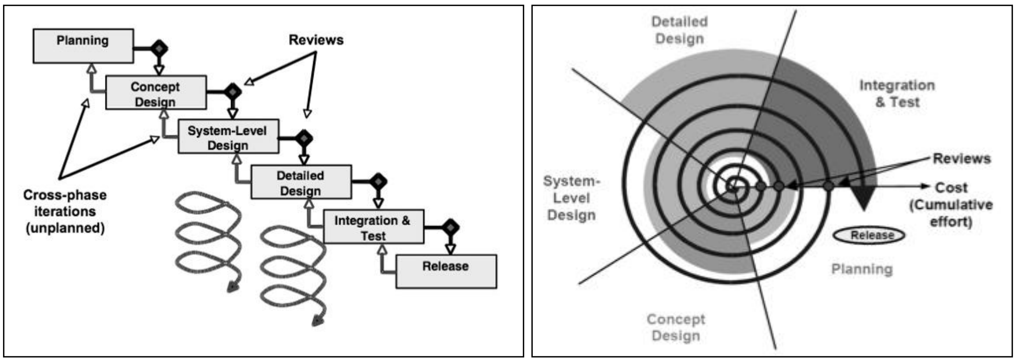

Figure 1: Waterfall (left) and spiral model (right) [6]

The gate to detailed design is the last point at which the project can be terminated before entering significant financial spending [10]. The uncertainty regarding the stability of customer requirements throughout the PDP is not directly addressed in the waterfall model, which can lead to unplanned and costly cross-phase iterations. Failure can furthermore result if early specs and assumptions are proven wrong by subsequent market research, detailed design or prototyping [9]. Company-internal and organizational uncertainties are reduced due to the clear structured activity and process guideline. Each stage consists of a set of planned activities, numerous milestones and periodic reviews and do not require significant management attention. Decisions at every gate are mainly based on detailed performance checklists and scoring models that serve as quality-control checkpoints. The first, most parts of the second and fourth principle of Risk-driven design is not addressed in the waterfall approach. In addition some sources of uncertainty are not considered, such as suppliers, market or competitors, which can lead to risks or missed opportunities. The waterfall model therefore performs well when product cycles have stable product definitions, the product uses well-understood technologies and the project is dominated by quality requirements. In these cases the PDP helps to find errors in the early stages of a project when costs of changes are low [9]. It is also desirable in those programs that require formal reviews that signify the completion of specific phases and which frequently form the basis for progress payments.

Table 1: Summary of the waterfall model risk management approach

Principle 1: Creating Transparency regarding Design Risks • Not addressed, no identification or quantifications of uncertainties or risks in the process
Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties • Checklist and scoring model after each stage to check if quality requirements are met • Preceding each stage is go or no-go decision point
Principle 3: Minimizing uncertainty in Design • System integration uncertainties are reduced with narrow iterations within and rigorous quality reviews after each phase • Customer uncertainties are reduced with heavy up-front market screens, evaluation and interpretation of customer needs • Company-internal uncertainties are reduced with clear structured and detailed action plans
Principle 4: Creating resilience in the Design Systems • Not addressed

3.2 Spiral Model

Unlike the waterfall PDP, in which functionality and specifications of the product are agreed upon at the start of the project, the spiral model begins with more difficult and poorly understood product components and incorporate easier components over time. Each cycle includes an initial assessment of continued risks for the upcoming cycle, and concludes with a review to establish validity of continued cross-phase iterations. The uncertainty of new and immature technology is reduced with continuous stakeholder integration and risk management: The PDP identifies, assesses and evaluates risk early in the cycle when costs of change are relatively low. With repeating regular steps, including concept development, system level design, detailed design, integration and testing, it furthermore provides a method for iteratively developing the product, while the project definition is still proceeding over time (see Figure 1). The spiral model is very well suited to reduce uncertainties regarding the stability of customer requirements. Due to considerations and commitments of critical stakeholders e.g. users, customers, developer and maintainer in every cycle, the long-term iterations can lead to flexible product adjustments to customer needs even in later phases of the PDP. However, the quality or effort of understanding customer requirements by the project team is just weakly addressed in the spiral process. Furthermore it should be noted that the spiral PDP is very complex and therefore also partly reduces company-internal uncertainties. Compared with the waterfall model, there is no clear guideline structure and no definitive total plan. Furthermore risk calculations are difficult in subsequent cycles and strongly rely on existing risk management expertise [18]. It requires significant management overhead and developer sophistication. Also, there are difficulties in the first spiral step in determining objectives, alternatives and constraints due to the lack of explicit process guidance [19]. Additionally Unger (2003) describes difficulties in defining objective and verifiable milestones that indicate the readiness to execute another iteration [9]. This factor can lead to significant delays in manufacturing and long lead times. The spiral PDP is therefore more appropriate for complex projects with “unstable” or poorly understood customer and/or performance requirements. Many authors describe the spiral PDP as a risk-driven approach [15, 17, 18, 27].

Decisions about the degree of performance details of each product, as well as the level of effort to be devoted to each activity within the cycles, are determined based on technology or performance risks [17, 18]. However, the associated probability of success of each activity is not considered in the decision making process. The spiral PDP includes go or no-go reviews based on stakeholder commitments. The main criteria, after which each cycle is judged, include whether the specific architecture of the product is supporting operational concepts, realize prototype results or satisfy the stakeholder requirements [18]. Compared with the waterfall model, these review procedure is much less rigid [9]. Due to its nature of cross-phase iterations with comprehensive risk evaluations in the beginning and the integration of stakeholder commitments and reviews throughout each cycle, the spiral model can detect and correct errors fast and flexible in the process and can adjust the objectives with low costs of change even in later phases of the development process.

Table 2: Summary of the spiral model risk management approach

Principle 1: Creating Transparency regarding Design Risks • Quantifying risks is weakly addressed due to the initial assessment of continued risks
Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties • Risk considerations are used to determine level of effort to be devoted to activities and to determine degree of performance details of the product • Less rigid go or no-go decisions after stakeholder commitments
Principle 3: Minimizing uncertainty in Design • Technology uncertainty is reduced with cross-phase iteration and risk management • Uncertainty due to the stability of customer needs is reduced with excessive stakeholder integration and commitment throughout the development process • Company-internal uncertainties are weakly reduced due to the complex process execution
Principle 4: Creating resilience in the Design Systems • Cross-phase iteration and stakeholder commitments allows fast and flexible error detection • Adjust objectives with low costs of change even in later phases

3.3 Design for Six Sigma

The second two PD approaches are shown in Figure 2. It should be noted that both principles are not prescriptive but integrated or supportive parts of the PDP and provide useful methods and philosophies for the development process. In this context, Design for Six Sigma (DfSS) explicitly addresses risk management in the early requirement phase (see Figure 2). The first principle is therefore strongly addressed regarding the identification of knowable uncertainties and the quantification of risks with an extensive toolset of respective methods [21]. The RADIOV (**R**equirement, **A**rchitecture, **D**esign, **I**ntegrate, **O**ptimize, **V**erify) process of Design for Six Sigma furthermore strongly reduces system integration and technology novelty uncertainties throughout the process with comprehensive quality methods to meet Six Sigma expectations e.g. TRIZ, DFMEA or Monte Carlo simulations. Critical product specifications are identified, assessed and prioritized regarding performance risks and feasibility in the Requirement phase. Customer expectations are translated to measurable product requirements and summarized in a quality system level of house [21]. Based on the developed key deliverables in the requirement phase, the following Architecture, Design, Integrate, Optimize and Verify phases subsequently integrate the product system.

DfSS also reduces supplier uncertainty in the last phase: The supply chain readiness is checked regarding the ability of delivering the product with pilot and early production samples. Used verification methods include DFMEA, lead time- or on time delivery model and product launch plan. DfSS is strongly oriented towards reducing customer requirement uncertainty in the requirement phase with an extensive voice of the customer (VOC) gathering. The goal of the VOC is to identify, assess, prioritize and predict the impact of customer requirements with methods like interviews, Kano Analysis, Conjoint Analysis, Customer Requirements Ranking or System Level of House [21].

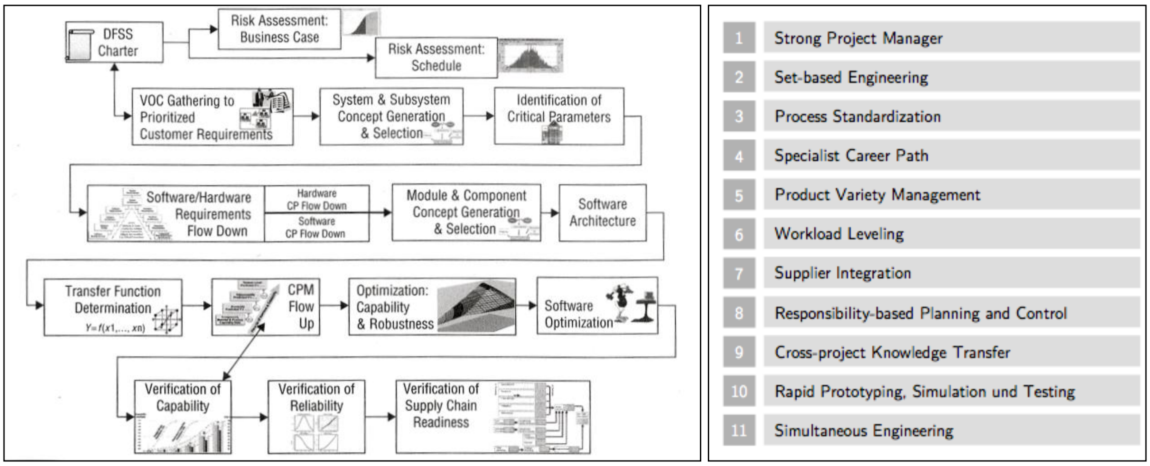

Figure 2: Design for Six Sigma (left) [21] and eleven principles of Lean PD (right) [24]

However, DfSS only partly addresses uncertainties regarding the stability of customer requirements throughout the process: After the requirement phase in the beginning of the RADIOV process, the customer expectations are frozen and translated as “key deliverables” for downstream processes. DfSS strongly reduces company-internal uncertainties due to its clear guided structure and the detailed methodical support within the different phases. It should be noted that the DfSS process is however complex and needs a lot of development sophistication and risk management expertise. The Schedule and Business case risk management processes in the requirement phase are used to both improve confidence and prioritize risks to business goals and schedule adherence. Unlike the spiral model, the project resources are not allocated to retire the biggest risks first, but to support the most profitable project. The project profitability is identified and evaluated based on financial or portfolio risk assessment in the business case phase. The comprehensive use of probability methods in these phases e.g. Monte Carlo simulations, make sure that project objectives are considered with the associated probability of success. Furthermore, based on this risk transparency, DfSS addresses entrepreneurial decision making through the aggregation of risks on the project level. Decisions about pursuing or to stop pursuing a project are made both based on quality checklists between the subsequent phases and on addressed key challenges in the business case. DfSS also addresses parts of responsiveness in development systems. Due to its focus on integrated quality in the process and transparency regarding influencing risk factors, DfSS leads to fewer changes and low costs of change because possible failure sources are transparent upfront. However, some aspects of a responsive development system such as versatility or cost efficiency are not directly addressed in DfSS. Yet it establishes generalized shared schedule buffer in the project plan to avoid personal buffer that can lead to schedule risk [21].

Table 3: Summary of the DfSS risk management approach

Principle 1: Creating Transparency regarding Design Risks • Identification and quantification of uncertainties and risks are strongly addressed with an extensive methodical toolset
Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties • Decision about resource allocation is based on probability functions of project profitability • Objectives are associated with the probability of success to support decision making • Entrepreneurial decision making is based on project risk aggregation • Go/No-go decisions based on meeting performance requirements
Principle 3: Minimizing uncertainty in Design • System integration and technology novelty uncertainties are reduced with comprehensive probability methods and risk management in the requirement phase • Customer requirements uncertainty is reduced with an intensive VOC gathering process • Company-internal uncertainties are reduced due to the clear guided process structure • Supplier uncertainty is reduced with methodical verification of the readiness level
Principle 4: Creating resilience in the Design Systems • Addresses some aspects of responsiveness (low costs of change, ability to detect errors quickly) • Aggregated “shared schedule buffer” in the project plan

3.4 Lean Product Development

We argue that Lean Product Development is an efficiency-driven approach that is focusing simultaneously on value creation and waste elimination in the PDP [28]. The creation of cost- and performance-buffers is contradictory to the concept of lean thinking. However, the main focus of Lean PD is to establishing a learning- and continuously improving organization [24]. It therefore strongly reduces company-internal and system integration uncertainty with an intensive efficiency-driven project execution. Some examples of how Lean PD components reduce these uncertainties are described in the following: The Strong Project Manager (SPM) is extensively involved in technical details, continuously reviews cost, schedule and performance targets of the project, is concerned with the integration of subsystems, and chooses the technology used for the product [24]. Cross-Project Knowledge Transfer is used to provide a company-wide knowledge database. The resources of the workforce are leveled evenly to avoid over- or underutilization. Product variety management is used to avoid large number of drawbacks that are connected with a high variety in products. An established specialist career path ensures continuous learning, high expertise and a standardized technical skillset of every manager. The SPM additionally reduces customer requirement uncertainty: He or she is responsible for investigating and defining customer value (voice of the customer) at the beginning of the project and has to evaluate the product throughout the PDP to meet customer expectations.

Table 4: Summary of Lean PD risk management approach

Principle 1: Creating Transparency regarding Design Risks • No identification or quantification of risks is addressed in the principle
Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties • Go/No-go decisions based on checklist and special "decision matrices"
Principle 3: Minimizing uncertainty in Design • System integration and company-internal uncertainty is reduced due to efficiency-driven project execution and maximizing value and minimizing waste in the process • Customer requirements uncertainty is reduced with investigating and defining voice of the customer by SPM • Supplier uncertainty is strongly reduced with an early and extensive integration in the project
Principle 4: Creating resilience in the Design Systems • Very well aligned regarding responsiveness (low costs of change due to Set-based engineering, flexible and quick error detection in the process, etc.) • Cost or performance buffers are contradictory to the concept of "lean thinking

However, the uncertainty due to the stability of customer requirements is not addressed by Lean PD: Although Set-Based Engineering, as a part of Lean PD, delays decisions to "establish feasibility before commitment" [29], the main focus at each gate is to manage system integration- and organizational uncertainties and not uncertainties due to changing customer requirements [29]. Unlike common development approaches, the suppliers are directly integrated in the development processes at an early stage and are actively supported to improve their performance [24]. In general, Lean PD does not directly adrdress Risk Management. Therefore decisions are basically made based on checklists and special matrices that facilitate the review of designs. Furthermore there is no direct process that identifies or quantifies risks or uncertainties. As already stated in the previous chapters, the efficiency-driven Lean PD can be defined as a responsive design system. For example, the costs of change are low due to Set-based engineering and the flexible, responsibility-based planning and control support quick error detections in the process. However, creating costs and performance buffer is contradictory to the concept of Lean Thinking [30].

4. COMPARISON AND INTERPRETATION OF RISK MANAGEMENT APPROACHES

All of the discussed product development approaches have different foci of managing risk in product design (see

Table 5). Other than DfSS, no discussed approach explicitly creates transparency regarding design risks up-front. As a consequence, the reduction of uncertainties focuses on pre-defined, ‘standard’ uncertainties and does not necessarily reflect the specifics of the project. This aspect might then lead to the implementation of isolated and retrospective risk management processes after major risks occurred during development. All PD approaches other than DfSS need improvement regarding risk identification and quantification, for example through the integration of the appropriate DfSS or risk management methods into the up-front planning and regular project reviews.

Table 5: Overview of Extend of Risk Management of Different PD Approaches

Risk-Driven Design Principles	**Waterfall/ Stage gate**	**Spiral**	**Design for Six Sigma**	**Lean PD**
1.) Creating transparency regarding design risks				
Explore and identify knowable uncertainties	○	○	●	○
Quantify resulting risks	○	◐	●	○
2.) Making risk-driven decisions				
Go/no-go decisions, quality checkpoints	●	◐	●	●
Resource allocation to retire biggest risks first	○	●	◐	○
Objective setting associated with risk assessment	○	◐	●	○
Entrepreneurial decision making based on risk-return analysis	○	○	●	○
3.) Minimizing uncertainty in design				
New (component) technology	◐	●	●	◐
System integration	●	◐	●	●
Quality of understanding customer requirements	●	◐	●	●
Stability of customer requirements	○	●	◐	○
Company-internal	●	◐	●	●
Competitor	○	○	○	○
Supplier	○	○	◐	●
Market	○	○	○	○
4.) Creating resilience in the design system				
Responsive design system	○	●	◐	●
Critical buffer in design system	○	○	◐	○

● … Strongly addressed ◐ … Weakly addressed ○ … Not addressed

Risk-based decision making is most strongly addressed by DfSS and partly by the spiral model. Spiral development directly allocates resources to retire the biggest quantified risks first through the iterative planning and execution of PD activities. The risk quantification process is however retrospective after every completed cycle and not necessarily predictive as in the case of DfSS. The waterfall or Lean PD approaches focus their decision-making process on quality checkpoints or milestone gates. In case of both the waterfall and spiral model, risk-return analyses could be incorporated into the early planning stages when specific development projects are chosen. They could also be used at each decision point where a decision between alternatives (e.g. technologies) has to be made. In the early planning phases of the waterfall model, the assessment of objectives or value propositions regarding their likelihood of success could also be integrated.

The different PD approaches address markedly different types of uncertainties. The waterfall model with its well-planned phases, rigid reviews and focus on clear structure mostly addresses system integration and company-internal uncertainties. Contrary, the spiral model focuses on comprehensive cross-phase iterations, the integration of critical stakeholders throughout the process and flexible reviews after several stages to reduce the uncertainty of changing customer requirements or technology novelty. DfSS addresses a larger number of risk sources with comprehensive probability assessments. Lean PD has some weaknesses regarding volatile customer requirements. Compared to the spiral model, it is not designed to handle significant changes in customer requirements in later development phases due to its very efficiency-driven design approach. It is, however, very well suited to make sure that (current) customer requirements are understood well. All approaches show a general weakness to address competition, supplier or market/environmental uncertainties. If any of these uncertainties post significant risks, the processes must be customized to include the appropriate treatment actions.

Creating a resilient design system is not in the focus of any of the discussed PD approaches. The aspects of responsive design systems are well addressed by the spiral model and Lean PD by their emphasis on fast and efficient processes. However, the creation of critical buffers is not explicitly considered in either case. Transparency regarding the projects risk exposure could form the basis for making a business case in favor of establishing critical buffers, and against excess buffers, in each PD approach. This would lead to a more robust PD approach that would be able to absorb risks sufficiently, especially in later design phases.

5 OUTLOOK

We have begun to validate and deepen the results of this theoretical discussion through interviews with PD risk management practitioners from the aerospace and defense industry, as well as case studies of the integration of risk management into PD processes. It proved helpful to discuss risk management not in terms of a risk management process, but along the four principles or 'goals' of risk management. This way, PD process inherent risk management capabilities could be better described and understood. For example, by using a spiral-type software development approach (Scrum) in one company, a number of uncertainties (changing customer requirements through incremental development, process efficiency through a close tracking of progress) were effectively addressed. Also, a detailed requirements tracking increased the responsiveness of the PD project, as risk impacts (both through changing customer requirements, as well as through not meeting performance targets) were quickly understood and matching corrective actions identified. Regarding a seamless risk management and PD process integration, one example that was documented concerns frequent risk identifications and assessments. These risk management processes were part of a number of PD processes, for example requirements analysis, project planning meetings, as well as intermediate and milestone reviews. Several interviews held to-date also confirmed our theoretical assessment of the risk management capabilities of the different PD processes. Both case studies and interviews will continue to provide a sufficient base for the validation and a richer description of the concepts outlined in this paper.

We also prepared a broad survey to further understand and describe how different PD approaches manage different types of risk, and how the respective gaps in those approaches are currently addressed. The long-term goal is to develop a method that maps the relevant uncertainties of a design project, recommends a suitable 'base PD approach' to execute the project, and augments the process where necessary by integrated risk management methods.

Based on our current industry findings, the discussion of design processes should be enlarged to include incremental software development approaches, such as Agile Development and Scrum. We are also planning to include a detailed discussion of set-based engineering in our future work.

Form the theoretical discussion in this paper, a combination of a spiral development with Design for Six Sigma methods yields the most comprehensive risk management oriented PD process. Future work will also address understanding how these two approaches can be combined effectively.

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REFERENCES

[1] ISO. *ISO 31000:2009(E) - Risk management - Principles and guidelines*. (International Organization for Standardization, Geneva, 2009).

[2] GAO. Defense acquisitions. Assessments of selected weapon programs. (United States Government Accountability Office, Washington, 2009).

[3] Oehmen, J., Ben-Daya, M., Seering, W. and Al-Salamah, M., Risk Management in Product Design: Current State, Conceptual Model and Future Research. *Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010*, 2010.

[4] Smith, P.G. and Merritt, G.M., *Proactive Risk Management - Controlling Uncertainty in Product Development*. (Productivity Press, New York, 2002).

[5] DoD. *Risk Management Guide for DoD Acquisition*. (United States Department of Defense, Office of the Secretary of Defense, Washington, D.C., 2006).

[6] Unger, D. and Eppinger, S., Comparing product development processes and managing risk. *International Journal of Product Development*, 2009, 8(4), pp382-402.
[7] Oehmen, J. and Seering, W., Risk-Driven Design Processes – Balancing Efficiency with Resilience in Product Design. In Birkhofer, H., ed. *The Future of Design Methodology* (Springer, London, 2011).
[8] Ulrich, K. and Eppinger, S., *Product design and development*. (McGraw-Hill Higher Education, 2008).
[9] Unger, D.W., Product development process design: improving development response to market, technical, and regulatory risks. (Massachusetts Institute of Technology, 2003).
[10] Cooper, R.G., *Winning at new products: Accelerating the process from idea to launch*. (Basic Books; Perseus, Reading Mass. , Great Britain, 2001).
[11] Smith, P.G. and Reinertsen, D.G., *Developing products in half the time*. (Van Nostrand Reinhold New York; Van Nostrand Reinhold, New York, 1991).
[12] Zhang, X., Hu, T., Dai, H. and Li, X., Software Development Methodologies, Trend and Implications. *Adopting the IS 2009 Model Curriculum: Challenges for Program Implementation*, 2010, pp173.
[13] IPL. Software testing and software development lifecycles. *working paper* 1997).
[14] Ferdowsi, B., Product development strategies in evolutionary acquisition. Master's thesis. (MIT Aeronautics and Astronautics, 2003).
[15] McConnell, S., *Rapid development*. (Microsoft Press Redmond, Wash., 1996).
[16] Khalifa, M. and Verner, J.M., Drivers for software development method usage. *Engineering Management, IEEE Transactions on*, 2000, 47(3), pp360-369.
[17] Boehm, B.W., A spiral model of software development and enhancement. *Computer*, 1988, 21(5), pp61-72.
[18] Boehm, B. and Hansen, W., *Spiral development: Experience, principles, and refinements*. (Carnegie-Mellon University, 2000).
[19] Boehm, B. and Bose, P., A collaborative spiral software process model based on theory W. In*, IEEE.* pp59-68
[20] Yang, K., El-Haik, B.S., Yang, K. and El-Haik, B., *Design for six sigma: A roadmap for product development*. (McGraw-Hill Professional; McGraw-Hill, New York, 2009).
[21] Maass, E. and McNair, P., *Applying Design for Six Sigma to Software and Hardware Systems*. (Prentice Hall Press Upper Saddle River, NJ, USA, 2009).
[22] Morgan, J.M. and Liker, J.K., *The Toyota product development system: integrating people, process, and technology*. (Productivity Press, New York, 2006).
[23] Kennedy, M. and Ward, A., *Product development for the lean enterprise: why Toyota's system is four times more productive and how you can implement it*. (Oaklea Press, 2003).
[24] Hoppmann, J., The Lean Innovation Roadmap – A Systematic Approach to Introducing Lean in Product Development Processes and Establishing a Learning Organization. Diploma Thesis. (TU Braunschweig, 2009).
[25] MacCormack, A., *Towards a contingent model of the new product development process: a comparative empirical study*. (Harvard Business School, 2000).
[26] MacCormack, A., Verganti, R. and Iansiti, M., Developing products on "Internet time": The anatomy of a flexible development process. *Management Science*, 2001, 47(1), pp133-150.
[27] Forsberg, K., Mooz, H. and Cotterman, H., *Visualizing project management: Models and frameworks for mastering complex systems*. (Wiley, 2005).
[28] Murman, E. and Allen, T., *Lean enterprise value: insights from MIT's lean aerospace initiative*. (Palgrave Macmillan, 2002).
[29] Sobek, D.K., Ward, A.C. and Liker, J.K., Toyota's principles of set-based concurrent engineering. *Sloan Management Review*, 1999, 40(2), pp67-84.
[30] Krafcik, J., Triumph of the lean production system. *Sloan Management Review*, 1988, 30(1), pp41-52.

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