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APPLYING LEAN THINKING TO RISK MANAGEMENT IN PRODUCT DEVELOPMENT

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Abstract

This paper re-conceptualizes risk management (RM) in product development (PD) through a lean thinking perspective. Arguably, risk management in PD projects became a victim of its own success. It is often implemented as a highly formalized, compliance driven activity, ending up disconnected from the actual value creation of the engineering task. Cost overrun, delay and low quality decision making is common in product development processes even if RM processes are in place. Product development is about reaching project objectives by gradually reducing uncertainty, but often fail to do so without delay or cost overrun. This paper explores the relationship between product development and risk management and proposes to make RM an integrated value adding part of PD. Through a literature review we identify the potential of re-conceptualizing RM through lean thinking. We then conceptualize an outline of how one could apply lean thinking to RM to create a simple, value focused and consensus-forming perspective on how to make RM a meaningful part of PD.

Keywords: Risk management, Lean design, Project management

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1 INTRODUCTION

New product development (PD) is inherently linked to taking and managing risks, as most activities can be interpreted as a structured reduction of uncertainty. A lack of proper risk management (RM) is one of the ten major challenges that plague large-scale new PD programs (Oehmen et al. 2014; Oehmen et al. 2012a). A study observed that almost half of the risks that occur are not being detected before they impact performance (Thamhain 2013).

Risk management, to some extent, became a victim of its own success. Due to its importance, it has been highly formalized and is subsequently implemented as a monolithic process framework. This had the unintended consequence that it developed into a specialist activity, disconnected from the actual value creation of the engineering task, and executed as a "tick the box" activity to satisfy high level governance, documentation and compliance requirements (Oehmen et al. 2012a). Literal compliance can drive a lack of meaning and create identities of non-participation (Wenger, 1999) and for many firms the reason for having RM is because they are told they are required to (Hubbard, 2009). Oehmen et al. (2014) state that the majority (around 70%) of what is generally considered "risk management best practice" has no confirmable effect on overall engineering project performance. Beauregard (2015) presented a case study where the RM only identified 20% of the initial uncertainties that were later found to influence cost overrun of a PD project. RM practices are often poorly adopted, lacking and ineffective (Olechowski et al., 2016) and according to Hubbard (2009) most RM methods are flawed in important ways and do not appear to 'work' or measurably reduce uncertainty.

While the immediate value of RM can be unclear, the outcome of not implementing RM properly is very clear: Examples include cost overrun, 'surprises', schedule drift, quality loss etc. Problems that arise in PD are solved reactively (firefighting) with crisis management instead of preventive RM (GAO 2010a; Oehmen et al. 2012a).

A significant element of PD is making decisions in highly uncertain environments with limited knowledge, which is why RM is such an important element. It is a paradox that one of the major objectives of PD is to reduce uncertainty or 'risk', but RM is often not an integrated, value adding part of the PD process and the PD 'culture' (Oehmen et al., 2014).

RM can benefit from focusing on value (Browning et al., 2002; Welo and Ringen, 2016) and there are critical decisions in PD that needs effective and value adding RM (Oehmen et al., 2010).

This paper points towards a need for improvement of RM in PD, especially in relation to 'rediscovering' how RM can explicitly and transparently support PD. RM are sometimes not aligned with the goals and values of PD and does not create value, which is related to the effectiveness and efficiency of RM (Oehmen et al. 2012a). The main problem we are addressing is the apparent lack of an efficient, effective, value adding RM in PD. The main question we address in this paper is if it is conceptually sound to address this problem by applying Lean thinking to RM. Lean has been proven beneficial in a number of contexts, including PD. Lean is an improvement philosophy that among other things, deals with efficiency, effectiveness and culture (Womack et al. 1990). The remainder of the paper explores if and to what degree it makes sense to conceptualize RM through a lean thinking lens. This paper presents a conceptual discussion: The contributions it puts forwards are: 1. A brief recapitulation of lean thinking in the context of PD; 2. An interpretation of the six lean principles for RM in PD. 3. Illustrative examples from industrial PD practice highlighting their relevance and 4. A first collection of suggestions for solution principles that lean thinking offers that may support RM practice in PD. The fundamental questions that lean thinking raises are: What is the value that RM can create; who are the internal and external customers of the RM activities; and how can we operationalize an adaptive, integrated approach to RM in PD that create value and reduce waste? This is the first attempt at reconceptualising RM in PD through a lean perspective using the six principles that the authors are aware of.

2 STATE OF THE ART IN RISK MANAGEMENT AND LEAN THINKING IN THE CONTEXT OF PD

2.1 Risk Management in PD projects

The ISO 31000 standard describes a framework for implementing RM and that RM should be a continuous process that supports the development and implementation of the strategy of an organisation (ISO, 2009). According to PMI, RM is an essential element in project success. It is an important activity and should be applied to all projects as an integral part of every aspect of managing the project, in every phase and in every process group (PMI, 2009). "RM should be an integral part of the management of each project. Quality RM, its implementation and integration of management systems represents a significant added value" (Susterova et al., 2012). Even though these definitions and recommendations exist we see that "...failures in the development of complex, large scale products and systems point towards weaknesses in the existing approaches (of RM)" and that "product development processes do not emphasize reduction of risks […]" (Oehmen and Seering, 2011). Often project managers do not implement RM (Bollinger, 2010). Two of the major management challenges that RM in PD currently faces are lack of stability, clarity and completeness of requirements & lack of proactive management of program uncertainties (GAO, 2010b; Oehmen et al., 2014).
A study of the most widely used RM processes showed that none of the RM methods analysed dealt with all 5 core process elements of the ISO31000 (Oehmen and Rebentisch, 2010a, 2010b) but Beauregard (2015), found that "…application of the ISO31000 standard RM process in a case company, generated a lot of semi structured data, which surpassed the individual engineer's ability to make sense of it". The scope of the RM should be adapted to the objectives of the PD. "If the RM activities are focused on achieving a high technical reliability, broader questions of risk to profitability and market share cannot be discussed" (Oehmen and Rebentisch, 2010a). The RM activities and their scope are intimately tied to many parts of the PD project and it is important for engineers and engineering managers to define and implement a value-creating PD RM process (Oehmen et al., 2010). "The proposal is that[...]customer value in PD equate with producing useful information that reduces performance risk" (Oehmen and Rebentisch, 2010a). Before applying lean thinking to RM in PD, we briefly go through the 6 basic principles of lean in PD.

2.2 Background: Lean Thinking in PD

After the initial success of lean production (Womack et al. 1990), a general theory of "lean thinking" developed (Womack & Jones 1996; Liker 2004). Lean thinking was subsequently successfully applied to a wide range of practices, including product development (Murman 2002; Ward 2014; Reinertsen 2009; Oppenheim 2011; Oehmen et al. 2012b; Rossi et al. 2017).
Lean thinking, fundamentally, is a philosophy improving effectiveness (i.e. quality of goal orientation), efficiency (i.e. cost/benefit ratio), and organizational culture (i.e. people orientation). Authors operationalize lean thinking through general organizational, management and leadership approaches supported by various combinations of method toolboxes and process frameworks. To give an effective overview of what lean thinking in PD is, we will give a brief summary of its objectives, i.e. a description of the 6 lean principles (Womack et al., 2003) in the following, based on their application in lean product development (Oppenheim 2011; Oehmen, et al. 2012b; Welo 2011; Rossi et al. 2017).

2.2.1 Lean Thinking Principle 1 in PD: Value - Capture the value defined by the customer stakeholders, who may be either external or internal

The external customer who pays for the system or service defines the final value for the deliverable. Internal customers receive the output of a task or activity and usually do not explicitly pay. In both cases, the customer stakeholder is the one who defines what constitutes value (Olsen and Welo, 2011). It is very important to capture both task and overall project value with precision, clarity, and completeness, to create a clear program strategy and avoid unnecessary rework before resource expenditures ramp up. For programs with a very long duration, external factors can change, and customer value expectations may need to be revisited, updated, or revised. Clearly, a careful balance is needed. On the one hand, constant change and instability must be avoided or the system costs will grow and the schedule will lengthen. On the other hand, customer value expectations or threats may change, and an original value proposition could become obsolete.

2.2.2 Lean Thinking Principle 2 in PD: Value Stream - Map the value stream by planning the PD project and eliminate waste

Map all end-to-end linked tasks, control/decision nodes, and the interconnecting flows necessary to realize customer value. During the mapping process, identify and eliminate all non-value-added activities, minimize all necessary non-value activities, and enable the remaining activities to flow without rework, backflow, or stopping (the flow is described in Principle 3). A key concept to grasp in moving from the manufacturing to the design domain is that in manufacturing, material is being transformed and moved, while in the latter, information is being transformed and moved. The term information flow refers to the packets of information (knowledge) created by different tasks, which flows to other tasks (e.g. design, analysis, test, review, decision, or integration) for subsequent value adding. There are several implications when applying lean thinking principles, techniques, and tools to an intangible medium that is as fluid as information. Careful detailed planning and program front loading, common or interoperable databases, rapid and pervasive communication of decisions using Intranets or personal communication and frequent integrative events for efficient real-time resolution of issues and decision making, stand-up meetings, or virtual reality reviews are some techniques to keep information flowing. Each task adds value if it increases the level of useful information and reduces risk in the context of delivering customer value.

2.2.3 Lean Thinking Principle 3 in PD: Flow - Flow the work through planned and streamlined value-adding steps and processes, without stopping or idle time or unplanned rework

To optimize flow, plan for the maximum concurrency of tasks. Robust capture of value, good enterprise-level preparations, and good PD project planning are necessary conditions for subsequent lean execution of the project. In engineering projects, legitimate engineering iterations are frequently needed to address “chicken versus egg” technical problems, but they tend to be time consuming and expensive if they cross disciplines. Lean flow encourages an efficient methodology of “fail early – fail often” through rapid architecting and discovery techniques during the early design phases. The Flow Principle also encourages techniques that obviate lengthy iterations, for example through design front-loading, trade space explorations, set-based designs, modular designs, legacy knowledge, and large margins. Where detailed cross-functional iterations are necessary, lean flow optimizes the iteration loops for overall value, while limiting the tasks within the loops to those that experience changes of state and optimizing their execution for best value.

2.2.4 Lean Thinking Principle 4 in PD: Pull - Let customer stakeholders pull value

In manufacturing, the ideal pull principle is implemented as the Just-in-Time (JIT) delivery of parts and materials to the needing station and to the external customer. In program applications, the pull principle has two important meanings: (1) the inclusion of any task in a PD project must be justified by a specific need or request from an internal or external stakeholder and coordinated with them; and (2) the task should be completed when the stakeholder needs the output because excessively early completion leads to "information obsolescence", including for example the effect of changing requirements or loss of implicit (context) knowledge. Late completion leads to schedule slip and destabilization of carefully planned task sequences in the project. Therefore, every task owner should be in close communication with the internal customers to fully understand their needs and expectations and to coordinate work, modalities, and deliverables. A customer who makes arbitrary demands prevents a lean outcome, and uncontrolled pull tends to create chaos.

2.2.5 Lean Thinking Principle 5 in PD: Perfection - Pursue perfection in all processes

Competition is a “race without a finish line,” requiring continuous improvements of processes and products. Yet, no organization can afford to spend resources improving everything on a continuous basis. To clarify the issue, there is a distinction between processes and process outputs. Perfecting and refining the work output of a given task must be bounded by the overall value or benefit proposition (e.g. market success and project budget and schedule), which defines when an output is good enough. Otherwise, the waste of over-processing occurs. Judgment of experienced domain specialists and engineers is required in close coordination with engineers and project managers who are responsible for overall flow of value. In contrast, engineering and other processes are continuously improved to increase competitiveness. Two features of lean help in prioritizing processes for improvement: (1) making all imperfections in the workplace visible to all; and (2) prioritizing to eliminate the biggest impediments to flow. Seeing problems as they appear in real time is conducive to making better decisions on corrective actions and better prioritization of improvements. When noticed early, imperfections tend to be easier and less expensive to fix; unnoticed early they tend to grow to crisis proportions and require extensive actions to mitigate.

2.2.6 Lean Thinking Principle 6 in PD: People orientation - Respect the people in your program

The heart of a lean organization is a culture that recognizes its people are the most important success factor and motivates and enables them to adopt high-performance work practices. In a lean PD project, people are encouraged to identify problems and imperfections honestly and openly in real time, brainstorm root causes and corrective actions without fear, and plan effective solutions together by consensus to prevent a problem from reoccurring. When issues arise, the system is blamed and not the messengers. Experienced and knowledgeable leaders lead and mentor, but also empower frontline employees to solve problems immediately. Such an environment requires a culture of mutual respect and trust, open and honest communication, and synergistic and cooperating relationships of all stakeholders.

2.3 Current Status of Lean Thinking in Risk Management

Lean PD and other frameworks have shown that a focus on value in PD is beneficial (Ward 2014; Ouden 2012; Welo 2011; Welo et al. 2013, Rossi et al., 2017). RM can add value in PD through value focused RM (Browning et al., 2002). This perspective is further expanded and explored by the following sources outlining various perspectives on how RM can add value in PD and other contexts by way of a lean RM. Seddigh & Alimohamadi (2009) argue that lean RM is about reducing waste in the RM process, applying the general lean best practices and tools to RM and that such an approach would be highly beneficial if operationalized. Beauregard (2015) presents lean RM as a supplement to ISO31000 consisting of a data driven RM and a 'lean RM' approach to reduce uncertain events early in the PD. It proposes a performance metric called 'surprises', defined as the uncertain events not captured in the initial stage of PD risk assessment. The results show that only 20% of the uncertain events that influence cost overrun were captured by the initial RM (Beauregard, 2015). Beauregard (2015) advocate benefits of frontloading RM using 'lean RM' metrics of surprises and datamining. Poblete et al. (2012) argue that we can do much better in RM and proposes to apply the principle of flow combined with theory of constraints to the RM.

According to Bollinger (2010), lean RM is "a combination of tightly estimating, optimal buffers and squeezing more of what can be ascertained from project current and historical information". It is about integrating the RM into regular project activities. Lean RM is adaptive and recognizes that probabilities and impact of risk changes over time. Learning and front-loading is encouraged and a new way of calculating 'buffers' on activities is demonstrated (Bollinger, 2010).

The literature shows that there have only been superficial and insular attempts of introducing aspects of lean thinking into PD RM. The existing literature fails to develop a coherent conceptual model of what lean RM is (or could be), and instead focuses on applying a (seemingly random) subset of lean-inspired methods. A potential in applying some form of lean thinking to the process of RM have been identified, but lean is a broad concept and the various efforts are scattered in different directions. None of the lean RM sources cover applying the 6 principles to RM in PD, though they highlight the potential of applying lean to RM, or some form of a 'lean RM'.

Lean is an improvement philosophy that deals with effectiveness, efficiency and culture, and we argue that these fit with the improvement needs of RM in PD.

3 APPLYING THE SIX LEAN PRINCIPLES TO RISK MANAGEMENT IN PRODUCT DEVELOPMENT

In the following section, we are developing a conceptual framework, applying each of the six lean thinking principles discussed in section 2 to the area of RM in PD. Each sub-section consists of three elements: 1. A brief verbalization of the lean thinking concept for RM in PD; 2. Illustrative case examples of risk management challenges that would be addressed by applying the proposed principles and 3. Possible solution examples from the rich solution space that existing lean thinking approaches provide in the context of PD. The overall purpose of this section is to explore whether the notion of applying lean thinking to RM in PD is conceptually sound, and if the results seem promising and

meaningful to warrant further exploration. The illustrative case examples, as well as the solution examples, are not meant to represent a complete list of researched cases, their purpose is to merely illustrate whether or not meaningful examples can be found.
The illustrative case examples are taken from anonymized empirical observations based on years of work experience by some of the authors in PD projects in different industries.

3.1 Lean Risk Management Principle 1: Value

3.1.1 Applying the Value Principle to Risk Management in PD

Lean risk management in PD clearly articulates the underlying value proposition to the internal customers of engaging in risk management activities. It clearly identifies who the internal customers of the risk management activities are, articulates their key planning and decision making situations, and the corresponding need for support in appropriately addressing uncertainties. Lean RM articulates how it supports creating transparency regarding uncertainty, its structured reduction, as well as the management of residual uncertainty. As value perspectives can change throughout a PD project, it adapts to new requirements.
Part of the value provided by lean RM is creating reusable knowledge regarding the most significant uncertainties and RM activities, and knowledge regarding the corresponding management activities.

3.1.2 Illustrative Example of a RM in PD Challenge Relating to Value

When a PD project was estimating schedules in the beginning of the project they signed off on a tight schedule and budget without knowing it. As the PD project progressed, fewer and fewer things became possible because of the miss-judgement of the inherent uncertainties exposed later in the process. Much of the preliminary design work by a subcontractor was re-done, creating more uncertainty during the project. The RM process did not provide value for the PD activities and the team did not understand the amount of uncertainties they were taking on. This resulted in many unknown unknowns, and key decisions that were not supported. The RM did not understand the needs of the PD project. If lean thinking had been applied to RM in this situation it could have put focus on providing value for the PD and an RM tailored to the needs of the PD could have been designed.

3.2 Lean Risk Management Principle 2: Value Stream

3.2.1 Applying the Value Stream Principle to Risk Management in PD

All risk-related are mapped into a start-to-finish product development process, including a mapping of dependencies and decision points. During the mapping process, non-value adding risk management activities are eliminated (i.e. those not directly fulfilling a demand of an internal customer), necessary non-value adding activities are minimized, and the remaining value-adding activities enabled to be executed without rework, backflow or interruption. In lean RM, the additional overall PD waste of "insufficient management of uncertainty" is included. Lean RM seamlessly integrates into the PD processes. The value stream perspective of lean RM enables maintaining open solution space until the project is finalized.

3.2.2 Illustrative Example of a RM in PD Challenge Relating to Value Stream

Illustrative example: A cross-disciplinary R&D department had a culture of ‘trial & error’ to fix issues with each product error but did not accumulate any strategic knowledge. It was observed that this poses a risk to the company as competitors were creating tools from their experience as a way of accumulating strategic knowledge to optimize the risk mitigation value stream. A lack of understanding of the RM value stream created a risk for the company.

3.3 Lean Risk Management Principle 3: Barrier free and synchronized information flow

3.3.1 Applying the Flow Principle to Risk Management in PD

Lean RM is characterized by a stable, interruption free execution of the RM activities. It makes RM a natural part of the PD project management process flow, and seeks to avoid unplanned iterations. Lean RM optimizes the execution of relevant RM activities without enforcing a monolithic RM process where not absolutely necessary. The results produced by the RM process are used by the internal customer immediately in their processes, without rework or reformatting.

3.3.2 Illustrative Example of a RM in PD Challenge Relating to Flow

Illustrative example: During a PD project, the concepts that were generated during ideation, were evaluated against different risk dimensions and the processes was constantly stopped for re-iterations on these unexpected, ever changing and 'new' RM perspectives. The team was switching between for instance work hazard for users, mechanical feasibility and risk of delay for the project instead of reviewing risk dimensions as a natural part of the PD flow. RM was not part of the process but kept demanding focus.

3.4 Lean Risk Management Principle 4: Pull based activation of RM activities

3.4.1 Applying the Pull Principle to Risk Management in PD

Lean RM provides support to the internal customer, JIT, based on the latest available information, and exactly when it is needed. It supports a pull approach of providing lean risk management services, so internal customers can also receive risk management support services outside of planned processes. Available RM services are clearly structured and communicated to potential internal customers and are easily accessible. This includes support services to mitigate the occurrence of unexpected risks.

3.4.2 Illustrative Example of a RM in PD Challenge Relating to Pull

A concept in a PD project was scrapped after one month of detail work because of work safety hazards it created that could have been foreseen by risk evaluating the concept for work safety earlier, which was part of the requirements. They did the right RM, but at the wrong time. Similarly, in a different instance a PD project was shut down because manufacturing and the core business department saw too big a risk for the user and the company reputation. The RM information was not requested or 'pulled' by the PD but they were evaluated on it when presenting their concept to the senior management.

3.5 Lean Risk Management Principle 5: Perfection

3.5.1 Applying the Perfection Principle to Risk Management in PD

Lean RM makes imperfections clearly visible on three levels: Imperfections of the RM and monitoring process, imperfections in the identified risk landscape, and imperfections in the mitigation activities. It constantly works to identify and improve the most relevant imperfections in a continuous organizational learning cycle. It clearly articulates how it measures the RM value add to a PD process. Lean RM conceptualizes ways to decide how to measure, improve and focus RM activities. It uses regular and open feedback from internal and external customers to adapt the risk management process and continually improve its value contribution to the project. Lean RM creates opportunities for employees to qualify themselves to become internal service provides and trainers. Lean RM enables know-how buildup and RM improvement via an internal community of practice.

3.5.2 Illustrative Example of a RM in PD Challenge Relating to Perfection

Illustrative example: A company had an RM process that did not provide feedback opportunities for the internal customer, or supported the re-use of knowledge. RM as executed caused significant additional work and re-work for the engineers, much of which was regarded as "waste" by them. However, there were no mechanisms to either make the risk management performance transparent, collect improvement suggestions, or engage in a constructive dialogue between risk managers and engineers. This was a very significant source of frustration, in addition to delays, for the project. The company were striving for 'perfection' through RM, but the way they did it was counterproductive.

3.6 Lean Risk Management Principle 6: Respect for engineers and employees

3.6.1 Applying the Respect for People Principle to Risk Management in PD

A lean risk management organization first and foremost respects the individuals and teams of the PD project, and puts their desire to perform professionally first. It takes a point of view as internal consultant, supporting engineers and project managers in the execution of their tasks. Lean RM recognizes that it is part of everybody's job and qualifies everyone to be a risk manager over time. The activation and involvement of a wide range of employee is seen as the most important enabler to identifying and mitigating risks. The responsibility for risk mitigation must go hand in hand with the ability to act. Lean RM empowers employees to identify, assess and mitigate risk through an uncertainty accepting and participatory risk 'culture' potentially saving PD projects, the company and even lives. It rewards people that prevent problems rather than 'firefighters' by avoiding to blame the messenger. It creates an honest, open, balanced and trustworthy risk culture.

3.6.2 Illustrative Example of a RM in PD Challenge Relating to Respect for People

Illustrative example 1: A consultancy relied on a chief engineer to constantly solve problems in many parts of his project and other projects, while also having project management duties. Employees were noticing uncertainties, but there were a lack of participation and they did not have mandate and support to act on them, and were hesitant to speak up. Over time the chief engineer's performance decreased as uncommunicated risks turned into issues, causing significant frustration and performance losses. The RM 'culture' poses a risk by not respecting the people.
Illustrative example 2: A company identified a problem that all its core products had been in the market for more than 5 years. As a countermeasure, the management hired a 'design-thinking' consultant to boost creativity and innovation. However, the project failed to produce any significant innovation. It turned out that the company had a culture of compliance rather than a culture of "daring", causing people to stick with the secure and safe solutions rather that experimenting with new ideas and concepts. A lack of healthy risk-taking culture stalled innovation.

3.6.3 Solution Principles to Support the 6 Lean RM Principles

Lean thinking in general and lean PD in particular has developed a range of lean solution principles to support the operationalization of lean thinking. Based on the preceding discussion and examples, it is not difficult to hypothesize how these can be adapted for use in the context of lean RM. For example:
Value Stream Mapping can be readily applied to existing RM processes. This will yield several benefits: 1. The value proposition of RM activities to internal and external customers will be clearly articulated (Value). 2. RM activities are analysed regarding the value contribution and waste component (Value Stream); 3. Integration opportunities for RM and PD processes are uncovered (Flow).
Standardization of risk management activities, combined with effective learning cycles (i.e. RM process revisions and RM master data revisions (e.g. risk identification checklists; typical impact ranges etc:), will improve RM process quality (Perfection), as well as contribute to a culture of trust and open communication (People).
Visual Management of key risk management processes and outcomes (e.g. risk burndown curves; key risk matrices) will contribute to an integrated management and communication approach (Flow), as well as enable decision makers to quickly articulate additional information needs (Pull).
Set-based Concurrent Engineering is an existing approach in lean PD that shows significant potential to explicitly integrate risk identification and mitigation components by, for example, explicitly prioritizing the key requirements uncertainties that are mitigated by the set-based design approach (Kerga, et al. 2014a; Kerga, et al. 2014b).
A3 Forms is a lean management tool that has already gained significant traction in RM practice in PD, where key risks are captured and communicated in a standardized, concise and visual way. This approach can be expanded and refined, as well as developed further to integrate risk and uncertainty knowledge into other A3 Forms in use in PD (Rossi et al., 2017).

4 CONCLUSIONS

The field of RM is highly organized and professional, but often fails to deliver value in PD projects. It is a paradox that PD is about uncertainty reduction but RM is not a natural part of PD, though it is potentially a value adding activity if integrated properly in PD. This paper demonstrated that one way to improve the status quo of RM is to reconceptualise RM through a lean thinking lens. It demonstrated that it is conceptually sound to apply lean thinking to RM in PD, and these examples and first solution ideas justify a further investigation. In particular, we applied the six lean principles to RM in PD, provided illustrative examples from practice outlining the challenges that they address, and provided examples of adapting existing lean solutions to improve RM practice. Each principle can contribute to solving part of the effectiveness and efficiency challenges that RM faces. Applying lean to RM uncovered an 'ideal' future state of RM that could be applied as a guideline to improve the current state of RM in a company. Perhaps this is the first small step towards a new era of projects that finish closer to schedule and uncover less surprises by focusing on RM through a lean perspective enabling 'design for uncertainty'. Applying lean thinking to RM in PD could position RM as a meaningful integrated part of PD that helps guide innovation and though decisions.

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