Next Generation Hardware Development: The Role of Technology Intelligence to Reduce Uncertainty in Agile New Product Development

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Abstract—**Companies are adapting their traditional development processes, aiming for project-specific designs that are referred to as "Agile Product Development" - flexible, adaptive and accelerated processes. Implementing these principles supports developers to react to challenges such as shortened innovation cycles. Still, agile product development is an endeavor with many uncertainties. Agile methods aim at reducing these uncertainties through a balancing of predictive work (e.g. information gathering, forecasting, planning) and adaptive work (e.g. prototyping, trial-and-error, validated learning). However, companies often fail at successfully conducting predictive work in order to avoid uncertainties in the product development process. Methods for forecasting and information generation have to date not been described in the context of agile new product development. The authors explore if and how the concept of technology intelligence – a widely used method of information generation – can be used for agile new product development. Based on the identified shortcomings of current technology intelligence, the authors draft an adjusted concept for agile technology intelligence. Underlying premises and suitable methods are presented and discussed as a first step towards a comprehensive methodology.**

I. INTRODUCTION

"New product success is predictable". These were the initial words in the introduction to Cooper and Kleinschmidt's popular work that promoted the stage-gate system for new product development in 1993 [1]. Today, this premise appears problematic. Shortened innovation cycles, the increased number of disruptive innovations and the rise of startups are just a few examples of indications that the world of today is less predictable than it used to be before. Rather, game-changing innovations can today alter the scope and nature of entire markets radically within a few years. Drastic events (so-called "black swans") can completely change or even destroy a firm's business within days. Customers bear a dramatically increased capacity to change product requirements in short time horizons. Thus, product success is today hardly predictable and at least less than it used to be in the early 1990's. The antithesis – that new product success is not predictable – can be reinforced empirically. Some studies find that a majority of New Product Development (NPD) projects fail to meet the planned cost, time and revenue goals. By a conservative account, at least 40% of new products fail to deliver the planned goals [2].

The field of NPD is currently drawing increased attention from practitioners and scholars as agile approaches gain popularity. While agile methods are widely used in the software industry, they have only recently started to spread in manufacturing and the development of physical products. Scientific literature on the topic is still scarce, but it is growing rapidly. Agile New Product Development (ANPD) methods rely on a set of principles and values that emphasize self-organization, visualization of progress, empirical testing, cross-functional teams and close interaction between individuals. In contrast to earlier approaches of NPD, these concepts do not claim that new product success is predictable. Rather, the agile logic considers empirical testing and experimenting the best way to develop products. The emphasis on experimentation means that final results no longer are planned ahead in detail; even the possibility of failure is considered an option. However, in contrast to traditional approaches of NPD, failures will occur much earlier in ANPD and therefore at lower costs [3]. One major obstacle within ANPD is the prevalence of uncertainty. Uncertainty can be defined as the "difference between the amount of information required to perform a particular task and the amount of information already possessed by the individual" [4]. Managing NPD proactively becomes increasingly difficult because uncertainties are an inherent element of future. While uncertainty cannot entirely be avoided, a reduction helps firms to improve the success rate of their NPD.

One possible way to reduce uncertainty in NPD, that has to date not been subject of scientific research, is the application of Technology Intelligence (TI) practices. TI is a widely used concept for manufacturing firms in the domain of technology management. It can be defined as a process of gathering, analyzing and communicating relevant technological information. The aim of this process is to identify risks and opportunities that prevail in a firm's environment and future. Firms use TI today to analyze their technological environment. By identifying possible future developments and assessing their likelihood as well as through delivering relevant technological information and insights, uncertainties are reduced. It is assumed that the concept of TI can at least partially be applied to the context of ANPD, because also in this context, uncertainties exist. Entailing technological aspects (e.g. functioning of groups of components) as well as market aspects (e.g. customer behavior), these uncertainties impose risks in the product development and challenge a firm's capacity to plan ahead. Following this line of argumentation, the goal of this article is to explore the use of TI in the context of ANPD. For this purpose, the basic concept of an "agile TI", i.e. an adapted variant of TI that serves the conditions of agile development best, is drafted and discussed.

The structure of this paper is the following. Section II presents the current literature in the fields of NPD, uncertainty and TI. It will be shown that uncertainties play a central role in the process of ANPD and that current methods of TI fail at adequately addressing the problem in the context of ANPD. In section III, a basic concept of agile TI is derived and discussed from the two perspectives of necessary requirements and suitable methods. Lastly, in section IV, concluding remarks and an outlook for future research on the topic are given.

II. EXISTING LITERATURE

A. New Product Development and Agile Hardware Development

The successful development and launch of new technologies and products is an essential task for companies. But, good ideas do not automatically result in workable, appealing products [5]. Moving new products from an idea to launch is a complex process, which is why a significant number of products or projects fail on their way to market. However, in many cases not the failure itself, but the late awareness is problematic, as valuable resources are wasted instead of using them for new promising ideas. Various approaches for the management of new NPD projects exist in literature as well as in practice. As shown in a study of 2011, the use of a defined NPD-process is essential for the success of product developing companies [6]. One of the first NPD approaches was the BAH model, developed by Booz, Allen and Hamilton in 1982 [7]. Today the Stage-Gate process developed by Cooper and Kleinschmidt [8] is one of the most prevalent models, whether in its original form or in modifications. Today, in many cases, one single and fixed process is not sufficient anymore and successful companies are using different or variable processes, trying to react to the varying level of risk and complexity of different development projects [9]. Business environments have changed significantly in the last years, becoming more and more globalized, fastened, competitive and thus much less predictable. Existing models are reaching their limits and are assumed to be not adaptive and flexible enough and too controlling and bureaucratic for future challenges in NPD [10–12]. Thus, NPD and existing processes are rethought or modified and new approaches developed.

One approach that was specifically designed to overcome the problems of highly rigid NPD processes is concurrent engineering, sometimes also referred to as simultaneous engineering. Concurrent engineering is a NPD approach that gained popularity in the 1980's that focusses on the parallelization of tasks using cross-functional teams [54]. A considerable strength of the method is that all phases of the lifecycle of a given product are considered simultaneously. A detailed description of concurrent engineering in the context of hardware development can be found in [55] and [56].

A promising approach to fulfill the demand for more flexibility, adaptivity and a higher acceleration is the use of agile methods. The idea of Agile New Product Development (ANPD) can be traced back to a 1986 Harvard Business Review Article by Takeuchi and Nonaka [13], in which a new approach to all-at-once product development, that several successful companies were using, was presented [3]. The agile approach is a holistic and flexible method that is based on empowered, self-organizing teams as well as on daily face-to-face communication and validated learning by trying-out. The agile method was further developed in software engineering in the 1990's. The agile approach is often dated back to the year 2001, when seventeen software developers proclaimed a set of underlying principles called the "agile manifesto". It is today among the most cited works on the topic of agile software development and consists of four values: (1) individuals and interactions over processes and tools, (2) working software over comprehensive documentation, (3) customer collaboration over contract negotiation and (4) responding to change over following a plan. These values express that certain approaches to NPD are preferable over others; however, it is important to notice that the less preferred elements are not refused generally.

In the software industry, various methods and processes have been developed and are today widely used standard. Some examples for development approaches using the agile principles are Scrum [14, 15], Dynamic Systems Development Method (DSDM) [16], Crystal [17] or Extreme Programming [18]. The different process models can be differentiated by their level of abstraction. Particularly Scrum – due to the high level of abstraction – is not limited to the use in software development projects but also suitable for any other development projects. For a successful implementation or use, project teams with a high level of process experience are required. The use of agile methods for hardware development has only developed in the most recent years and scientific literature is still scarce. Despite this, manufacturing firms are increasingly incorporate agile values into their traditional NPD processes as they try to shorten lead time, reduce development costs and increase customer satisfaction. Both research and practice show that, adapting agile methods like scrum for hardware development presents a challenging endeavor. The difficulties arise from a few immanent differences between software development (which is intangible) and hardware development (which is restraint by the physical nature of products). Main differences between software and hardware development are discussed in a recent paper [19].

Given these challenges, a common proceeding for manufacturing firms in order to make their product development processes more agile, is to adapt existing stage-gate approaches so that they become less plan-driven and rigid but instead more prone to adaption, iteration and probing. This can be achieved in various ways. Sommer et al. outlined a "manufacturing scrum framework" that combines stage-gate NPD with scrum [20]. In this framework, the planning level of strategic project management (i.e. portfolio management and steering committees) is approached with stage-gate methods, whereas the project execution is done using scrum. While their study shows that a hybrid combination of agile and stage-gate processes can lead to significant performance increases in hardware NPD in a wide range of industries, this is only one of several possible proceedings to change from traditional to ANPD methods. Similarly, Cooper proposes an adapted stage-gate process that incorporates elements of the agile manifesto [11]. In addition, his framework includes a contingency-based risk model, where projects with a low risk assessment undergo an agile fast-track stage-gate process with few gates whereas high-risk major projects undergo a more linear development process that resembles the traditional stage-gate approach. This newer adaptation of the stage-gate methodology should be distinguished from the original approach that is more sequential and rigid. Variations of the latter are subsequently referred to as "traditional stage-gate approaches".

B. Uncertainties in New Product Development

Uncertainty can be defined as "the difference between the amount of information required to perform a particular task and the amount of information already possessed by the individual" as Galbraith proposes [21]. As such, uncertainty is characterized by an information lack. This presents the constituting problem of uncertainty. It is a problem because planning activities become risk-afflicted when uncertainty prevails. Consequences are, among else, time delays, waste of resources and difficulties in project planning [22]. As Frishammar et al. find, a high degree of uncertainty increases the probability of a project to fail. Specifically, technological uncertainty will challenge prototype development proficiency while market uncertainty influences both product launch proficiency and market forecast accuracy negatively [22].

Baker and Hart [5] described the types of uncertainty that are connected to NPD. In their analysis, the product development process is idealized and divided in three phases: Idea-Concept, Development and Launch. As shown in TABLE I, two categories can be distinguished. Uncertainties in the development phase are primarily rooted in the domains of technology and markets. Market-based uncertainties are primarily knitted to the fact that customer behavior is hardly predictable. They prevail as long as it remains unclear whether there is a strong, stable need for the product that customers perceive as valuable. Technology-based uncertainties are knitted to the questions whether the technology will deliver the promised customer benefit, or whether it will become a standard as well as whether the organization has the know-how, resources, capabilities and cooperating partners (such as suppliers) to be able to develop a given technology. In many cases, a flawed technology as part of a product, will be reason enough for the entire product development to fail, delay or have high cost increases. Examples where this is the case are technologies that fail to meet regulatory demands, products where the technology fails to deliver the designed beneficial advantage over competitor products or products that cannot be produced at acceptable prices.

Uncertainties are highest in the early stages of NPD (i.e. in the fuzzy front end of innovation). This is because the development process rests on a collection of assumptions. These assumptions characterize the product idea. Apart from assumptions concerning the capabilities of the development team and its firm, the underlying assumptions of the product idea address market issues (e.g. expected customer needs and preferences) and technology issues (e.g. expected performance of applied technologies and components). As the product development process proceeds, uncertainties are reduced. At the final step of NPD, when the product has just been launched, uncertainties have largely cleared. This is because the unknowns concerning market and technology issues turned into certainties as the product success was tested in practice.

TABLE I

Types of uncertainty	**Critical Questions**	**Stages in process**		
		Idea-Concept	***Development***	***Launch***
Market-based	Is there customer need for the product?	X		
	How stable is the need in the long term?	X		X
	How strongly is the need felt?	X		X
	Is the market big enough?	X		
	Do we have access to distribution?	X		
	Do we have experience in this market?	X		
	Do customers perceive value in use?	X	X	X
Technology-based	Can the chosen technology deliver the benefit?		X	
	Will the technology become the standard?		X	
	Do we have knowledge of the chosen technology?		X	
	Do we have manufacturing capability for the chosen technology?		X	
	Which OEMs/suppliers do we collaborate with?		X	

The way that uncertainties are approached marks a main difference between agile methods and classical linear approaches. As Sola et al. bring it to the point, all classical NPD methodologies "assume that the right product has been selected and that the main emphasis should be on its development" [23]. Thus, in these classical approaches, the product idea itself is mainly considered a premise, since possible uncertainties have been cleared in the selection process before the development has started. Thorough research and planning activities ensured that the right product idea had been chosen. Agile methodologies treat assumptions not as premises unless/ until they have been tested, at least in a rudimental fashion, under reality conditions. Thus, the product idea itself is considered an uncertainty and the main strategy to reduce uncertainty is early testing. Rubin [3] takes a similar viewpoint that is illustrated in **Figure 1**. From his perspective, both linear and ANPD approaches deal with the challenge of uncertainties that need to be reduced during the development process. However, linear methods primarily aim at reducing uncertainties through predictive work that happens anticipatively (up-front). Through diligent planning, information gathering, systematic assessment and forecasting, the risks of failure in product development are minimized. However, agile approaches to NPD aim at reducing uncertainties mainly through adaptive work that happens just-in-time. Through probing and adapting in short, highly iterative cycles, risks of project failure are mitigated because important assumptions are tested quickly in each iteration loop. The underlying assumption of ANPD methods is that excessive predictive work is meaningless because success-critical unknowns of the envisioned product such as detailed requirements are virtually unpredictable, but must be probed in the development process. In the ANPD context, Rubin advocates for a balancing of predictive and adaptive work (with an emphasis on adaptive work), claiming that excessive predictive work results in guessing, whereas excessive adaptive work leads to chaos [3].

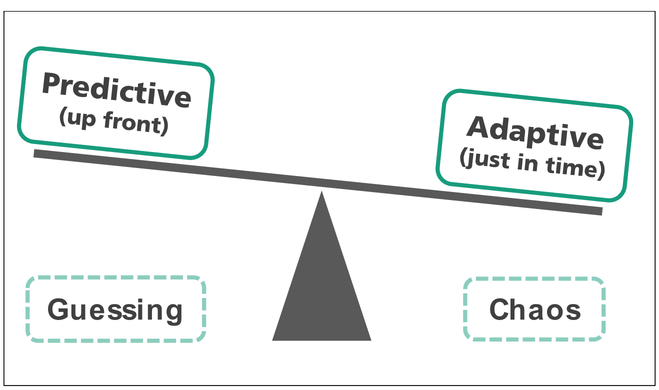

Figure 1. Balancing predictive and adaptive work

In startup management, a similar line of argumentation is advocated. According to Ries, the high likelihood of startup failure is rooted in the problem that lays in the "allure of a good plan, a solid strategy and thorough market research", when in fact these domains are far less plannable [24]. His concept Lean Startup (validated learning through highly iterative probing) shows striking parallels to the methods of ANPD. Both the concept of Agility and Lean Startup are based on the idea that although uncertainty cannot be avoided in management, firms can learn to successfully handle it and create innovation. Supporting this, research has indicated that agile approaches work best in situations where uncertainty is high [25].

It is important to notice that uncertainty has not only negative consequences for NPD. Scholars highlight the importance of uncertainty as a catalyst for the generation of ideas and new approaches, particularly in the fuzzy front end of innovation [26]. However, as elaborated earlier, a high degree of uncertainty will dramatically increase the risks of NPD. Uncertainty should thus be managed in a way such that it is reduced to a level that allows both creative idea generation and anticipative acting (e.g. predictive work, planning, decisions with long-term impact etc.).

C. Technology Intelligence

Technology Intelligence (TI) can be defined as the process of gathering, analyzing and communicating of relevant technological information. The aim of this process is to provide an information basis for decision-making in order to exploit chances and avoid risks imposed by changes in the (technological) environment [27], [28]. The process goal is a timely allocation of relevant information on technological trends in the business environment and to identify potential opportunities and threats [29], [30]. The term TI is often used interchangeably with similar terms. While TI deals with issues that are relevant from a technological viewpoint, other forecasting and intelligence methods (e.g. competitive intelligence, corporate forecasting, environmental scanning, market intelligence etc.) also entail non-technological business topics. However, it is not entirely possible to separate these concepts. This is because a comprehensive consideration of a technology will not be realistic without the simultaneous examination of commercial aspects (customers, markets etc.).

Three basic activities of TI are used in practice and described in academic literature: scanning, monitoring and scouting. While scanning aims at broadly assessing weak signals that point at any kind of technological innovation or change in the future [31], monitoring focuses on selected search fields which are profoundly analyzed over longer periods of time [32]. Lastly, scouting provides detailed information about specific technologies [33]. An important part of TI is forecasting, i.e. the generation of insights regarding future developments, their likelihood and possible consequences. Roots of the forecast development can be attributed to Ansoff's proclaim that environmental changes are heralded by vague precursors called "weak signals" [34]. According to another definition by Lichtenthaler, TI entails the systematic and continuous observation and evaluation of technological trends as a core process part of technology management [30]. Rohrbeck defines three roles of corporate foresight to be distinguished, the initiating role, the opponent role and the strategist role [35]. In the initiating role, foresight triggers innovation initiatives, such as R&D projects. In this role, the purpose of forecasting is to feed the front end of the innovation funnel. The strategist role is not directly linked to the innovation process, but supports it indirectly. In this role, forecasting provides strategic guidance, insights for innovation portfolio planning and identifies new business opportunities. Lastly, the opponent role has the primary aim of challenging existing ideas and assumptions of innovation activities against insights on external disruptions, new developments and other external changes.

TI processes are typically adapted to a firm's characteristics including size, culture, organizational aspects, market properties and business strategy. From a scientific point of view, TI has been adapted for specialized application scenarios like small and medium sized businesses [36], [37]. However, TI as a specifically designed concept for agile hardware development environments has not been subject of scientific studies to date. As a consequence, it is unclear whether the existing methods can be used or if they need to be adapted.

III. AGILE TECHNOLOGY INTELLIGENCE

Following widely accepted definitions from the academic literature, uncertainty has been characterized by information lack. It is arguable that technology intelligence – a process of generating insights and information – can play an effective role in reducing uncertainty in agile hardware development. The review of existing literature showed that current methods of TI are not designed for ANPD. The suitability will therefore be analyzed subsequently. The authors then outline how uncertainty can be mitigated with a rightfully conducted intelligence process, namely agile TI. The basic principles of an agile TI are outlined and discussed from two perspectives. First, the fundamental requirements are derived through a discussion of the general topics of TI. Secondly, additional suitable methods for the reduction of uncertainty are identified from existing literature and analyzed with regard to their suitability.

A. Requirements for Agile Technology Intelligence

The overall goal of this paper is to assess how TI methodologies can support firms that use agile approaches to increase their NPD success. One focus of consideration will be the question how uncertainty can be reduced through the application of TI methods. As described earlier, a reduction of uncertainty improves a firm's capability to successfully develop new products. Subsequently, it is discussed if the existing concept of TI is suitable in order to achieve these goals. Additionally, new directions for designing an agile TI (i.e. one that serves ANPD processes best) are proposed. The consideration of TI requirements is twofold. In a first step, the general topics of TI are considered. These are the concepts that define TI. As a result of this discussion, it can be assessed whether fundamental concepts of TI need alteration before TI can successfully be used in the context of ANPD. Secondly, it is discussed how uncertainty reduction can best be achieved. For this purpose, both market and technological uncertainties will be examined and possible solutions discussed.

The subsequent discussion of general topics will address various areas (shown in TABLE II). TI has previously been described as a process that supports decision-making by providing guiding information. The TI process starts with the identification of information needs, after which the relevant information is gathered. The information is then assessed (interpreted, edited) and finally communicated (disseminated) [38]. The underlying assumption is that decision makers are enlightened by the outcomes of TI which improves their decisions.

There are two shortcomings of this perspective, when agile methods are concerned. Firstly, the sequential approach of gathering and assessing information is problematic when uncertainty is high. Boone and Snowden find that in these domains, knowledge is hardly created through analytic methods but generated through learning with experimental approaches [25]. Such experimental approaches are a cornerstone of ANPD. Secondly, considering TI a support process of information generation implies that there is some form of separation between decision-making and information gathering. In practice, information researching is often conducted by designated experts that work part time or full time on TI activities. They then hand the information to the relevant decision makers. However, a main agile principle is that empowered, interdisciplinary teams contain all the experts that are needed for their development task and that the team mainly learns through experimenting rather than "receiving" information. Also, separating information gathering and decision making creates an additional interface where typically information is lost. This is because an individual can only limitedly share implicit knowledge with other individuals, but it will use the full extent of implicit knowledge in decision-making [39]. We therefore propose that the general role of agile TI should be broader defined as an enabler for a firm to cope with complex, changing markets and technologies. From this viewpoint, TI serves to increase the development team's capability to learn.

Moreover, the scope of TI activities should be defined for agile contexts. Traditionally, business intelligence is conducted separately from TI. This is problematic because, typically, a new product will only be successful if both the technological requirements (e.g. the technologies enable the envisioned features) and the market requirements (e.g. customers are willing to pay for the features of the product) are met. If only one of the two domains is handled with success, there will not be a successful product. A possible solution could be to broaden the scope of TI activities to entail all relevant kinds of business information.

TABLE II

General Topics	Traditional vs. Agile Technology Intelligence	
	Traditional TI	***Proposed Agile TI***
General Role of TI	TI as a *support process* that delivers information	TI as an *enabler* for the firm to cope with complex, changing markets and technologies
Decisions & Information	Decision-making and information generation mainly separated	Decision-making and information generation to be conducted by the same individuals
Nature of information generation	Mainly analytic	Mainly experimental
Scope of TI	Business intelligence is conducted separately from TI	No separation between business intelligence and TI

B. Methods to Reduce Uncertainty

In ANPD, uncertainties are – in contrast to traditional NPD approaches – typically reduced through early testing and validation of underlying assumptions. To a certain degree, testing and validation can be achieved without building the entire product. Based on a literature analysis, methods are presented that allow for an early testing and validation. Both market-based as well as technology-based uncertainties are addressed.

1) Market-based Uncertainties

Market-based uncertainties may arise from various domains like regulation or competition. Most importantly however, and a focus of this investigation, are customer-induced uncertainties (the term "customer" is for the scope of this argument used synonymously with "user", since a distinction is problematic when products are concerned that are not yet fully developed). Customers imply a great degree of uncertainty because their behavior is hardly predictable; nonetheless is it decisive for product success. Customer orientation has therefore been highlighted as a critical factor in NPD [40]. One strategy to reduce market-based uncertainties is early customer involvement. It is believed that customer involvement helps to align the development process with the needs of the customers and therefore increases the success rate of NPD [41], [42]. There are many ways in which customers can be included in the product development. The authors conducted a literature analysis in order to find methods that appear suitable for this purpose; the results are presented in TABLE III. As outlined, the methods involve customers in very different ways. While surveys generate insights through questionnaires, where the user remains rather passive, other methods aim at a more active role of the user in the NPD process which is often preferable with regard to the generated feedback. Co-creation and open innovation methods claim an active role of the customers who are presented with incentives to share their ideas. Their main benefit is that a great number of users may autonomously experiment with product ideas. The Lead User Method typically only involves a smaller number of users but since lead users are experts on the product, their feedback is very detailed and validated [47]. The Empathic design approach emphasizes customers' feelings toward a product and is mainly used in Business-to-Customer environments. One major benefit is that it is the only method that focusses on the feelings of the customer. The method is therefore a good supplement to other approaches [43]. Product clinics are a promising method to improve the development status of a product. Customers deal with products or prototypes in a prepared laboratory-like setting while they are being observed. An advantage of this method is that the product is being experienced by the customers and user-interaction can thus be revealed [43]. Lastly, Toolkits for innovation are a collection of tools that enable users to experiment with a product and thus delegate the task of innovation to the users. The main benefit of this proceeding is that the innovation starts with the users themselves who have the best insight into their specific needs [48].

It is beyond the scope of this investigation to further assess and validate the suitability of the presented methods. Instead, the intention is to demonstrate possible approaches that help to reduce market-based uncertainties. Practitioners or scholars may in a next step validate the results. Nonetheless the results show that there are various ways of integrating customers into the process of ANPD so that market-based uncertainties can be reduced. Further research is needed to establish how these methods should ideally be combined with traditional proceedings of information gathering.

One challenge in the field of early customer involvement is the often hypothetical nature of the investigation as a consequence of the circumstance that parts of the products are not developed at the time. Users are therefore confronted with hypothetical descriptions that fill the void. The problem is that users often lack the capability to fully imagine the product, its usage and benefits. For a successful customer involvement it is therefore crucial to make the product somewhat "experienceable". Only if users can physically interact with the product in close-to-reality settings, may the potential of their feedback and idea generation fully be exploited. Further research should therefore explore how even rudimentary products in early stages of the development can be presented to users such that their main features are experienced by the customers in real world settings.

TABLE III

Method	Methods for Reducing Market-Based Uncertainties	
	Description	***Advantages***
Survey [43]	Method used in practice as well as in research to gather opinion or knowledge from customers by disseminating and evaluating a questionnaire	+ Quick and cost-efficient implementation since no physical prototype necessary + Identification of industry trends, an organization's strengths and weaknesses, areas of improvement etc. is easily achievable
Co-creation and Open Innovation [42, 44–46]	Enabling users to autonomously experiment and innovate by providing a platform for collaborative innovation	+ The possibility of autonomous experimenting by users unleashes a great potential of ideas that can improve the product + Co-creation reaches a large group of people to be involved in the innovation process
Lead User Method [47]	Lead users are particularly advanced customers who will benefit from the solution to a particular customer problem that is relevant for the future	+ Since lead users are experts on the product, they combine the "customer view" with in-depth knowledge and expertise about the product + The method is widespread and has been successfully implemented in various industries
Empathic Design [43]	Empathic design is a user-centered design approach that highlights the user's feelings toward a product.	+ The exploration of customer needs from an emotional perspective is an opt supplement to other methods (e.g. surveys) that often fail at revealing user's feelings toward a product
Product Clinic [43]	Customers deal with specific products in a prepared laboratory-like setting while they are being observed	+ Feedback on a product can be gathered very quickly + In a rightfully prepared setting, the product can be made "experienceable" and concrete ways of user-interaction can be revealed
Toolkits for Innovation [48]	Toolkits for Innovation enable users themselves to innovate the product through probing and experimenting. They are thus a means to eliminate exchange of need-related information between users and manufacturers.	+ Specific needs that are difficult to communicate to product developers can be handled by the users of toolkits for innovation + Toolkits for Innovation are particularly useful in settings where highly customized products require complex communication between customers and manufacturers as often seen in the Business-to-Business segment

2) Technology-based Uncertainties

Technology-based uncertainties exist because the product vision typically contains important technological assumptions that might turn out to be wrong at a later stage. An effective way to reduce uncertainties is to verify (or falsify) these assumptions as early as possible. Even though a final verification of all assumptions can only be done once a full functioning prototype has been built, it is possible to reinforce or neglect them in earlier stages. The authors argue that it is of paramount importance to challenge underlying technological assumptions both through knowledge from outside the firm and through placing designed parts in close-to-reality environment testing (this can be in a physical setting or a kind of simulation) as early as possible. These two proceedings are critical in reducing what is referred to as the "unknown unknowns". Opposed to "known unknowns", which in essence are risks that one is aware of, "unknown unknows" are risks one is not aware of. The emergence of such risks is a characteristic property of complex systems and is often decisive in technological NPD projects.

TABLE IV presents methods that address the problem of uncertainties. The results of an explorative literature analysis are presented with the aim of triggering a scientific discussion about suitable approaches in order to mitigate technology related risks in ANPD.

TABLE IV

Method	Methods for Reducing Technology-Based Uncertainties	
	Description	***Advantages***
Knowledge Sourcing in Networks [49]	A widespread proceeding by firms and organisations to acquire and utilise external sources of knowledge and technology	+ By being a member of an innovation network a firm can lower the risks of technological failure, as the burden for exploiting the new technology is no longer carried by one firm only + Competencies can be used more efficiently in networks
Supplier Integration [50]	Integrating the supplier in the product development process by either by delegating development tasks or through collaborative development	+ Collaboration may produce better products, at lower costs since a broader base of competences is used + Synergy effects as well as specialization effects possible
Field Testing and Beta Testing [51]	Field Testing means the product as a whole is tested under real-world conditions instead of in a laboratory setting. Beta testing can be described as user acceptance testing; models are subjected to real world testing by the intended audience for the product	+ Real world conditions are the setting that provides for the highest possible validation of assumptions + For new products, products introducing substantial new functionality, or products aimed at a small defined audience, beta offers the ability to achieve legitimate customer acceptance, ensuring the product meets the requirements of its audience
Simulation and Functional Digital Mock-Up's [52, 53]	A mathematical, geometrical and functional digital representation of a product and its functionality	+ Simulation provide an animated 3D graphical representation of your product; this improves the understanding of how the system, will work and also provides visual feedback regarding potential problems or issues that may not be intuitive

Four suitable methods were identified. The first, Knowledge Sourcing in Networks is a method of integrating firms with relevant technological competencies into the ANPD process. Whereas collaboration between firms has always existed, the idea is increasingly applied more comprehensively in so-called innovation networks. The firms in these networks do not only collaborate within specified bilateral projects but share knowledge and insights on all business-relevant topics. Their main advantage is that the firm's competencies can be used more efficiently in the network, which reduces the risks of failure or delays in the NPD process. A similar approach, Supplier Integration, aims at integrating the suppliers into the NPD. In the context of agile methodologies, this integration does typically not happen on a merely contractual basis, but on the basis of a trustful and communicative relationship that is based on mutual interests. To date, however, research has not yet established widely accepted proceedings for supplier integration in ANDP. Field Testing and Beta Testing are approaches that aim at validating functionality and usability of the product in a real-world environment and are conducted in almost any NPD process. Typically, field and beta testing occurs at the late stages of the development since a high degree of product readiness is required under real world conditions. However, from the perspective of uncertainty reduction, it should be conducted as early as possible. In order to achieve this, rudimentary prototypes are needed that only validate the most critical elements of the product. Further research is needed to assess how rudimentary these prototypes have to be, i.e. which elements are critical and which can be neglected in early stages, for an optimal reduction of risks in the development. Lastly, Functional Digital Mock-Up's and Simulation methods can be considered a complement to physical testing. Simulations are digital representations of the product and its functionality and they are therefore particularly useful under circumstances where physical testing cannot be achieved due to technological difficulties, high costs or too long required lapses of time.

Current methods of TI use an analytic approach to generate insights, which happens through gathering and interpreting information. The presented methods for uncertainty reduction are not solely analytic but also experimental. Experimental proceedings have the advantage that the generated information has a very high degree of validation. From the author's viewpoint, they therefore constitute a suitable addition to the tools that are currently being used in TI. Experimental approaches to generating insights are widespread in startups, particularly the Lean Startup method by Eric Ries [24]. In order to further design the concept of agile TI, inspiration can be used from this method. In a next step, it should be assessed how both analytic and experimental approaches can be combined to generate insights.

IV. CONCLUDING REMARKS AND OUTLOOK

Intended as a discussion paper, the overall aim of this article was to explore the use of technology intelligence in the context of agile new product development. ANPD is characterized by a high degree of market-based and technology-based uncertainty which imposes harmful challenges to firms in their innovation efforts. It was argued that uncertainty consists foremost of an information deficit. Thus, the concept of TI – understood as a process of information generation – can help to reduce this information deficit (and thus uncertainty). However, the investigation of the current methodology of TI showed that it is in several ways insufficient for the use in an agile context.

Based on the shortcomings of current TI, the basic concept for an agile TI was drafted. Shortcomings are, among else, due to the almost solely analytic nature of information gathering in traditional TI while ANPD requires insights with a higher degree of validation that can only be achieved through testing under (close to) real world conditions. Another shortcoming of traditional TI is its definition as a support process that generates information that subsequently is communicated to decision makers. This implies an interface, where the information is communicated, but this interface is also inevitably associated with information loss. The proposal of this paper is that agile TI should be defined an enabler for the firm to cope with complex, changing markets and technologies, rather than purely a support process that delivers information. This broader viewpoint has the advantage that information generation and decision making do not necessarily have to be separate and an information loss can be avoided.

The analysis of suitable methods to reduce uncertainties in the development process showed that there are several methods that can be used for agile TI. In order to reduce market-based uncertainties, methods that include customers in early phases of ANPD are particularly promising. Examples are Product Clinics, Lead User Method, Co-Creation and Open Innovation as well as Toolkits for Innovation. For a reduction of technology-based uncertainties, methods that challenge the underlying technological assumptions of the product through testing, appear most suitable. This testing can either be physical (as the case with field testing and beta testing) or digital (as the case with Simulation and Functional Digital Mock-Up's). Also, methods that integrate competencies from other firms, such as Knowledge Sourcing in Networks, were found suitable.

As a next step for scholarly work on the issue, a framework is needed to describe an agile TI. This framework should address the organization of TI activities, the roles and responsibilities, limitations, resource allocation and cultural aspects. Further research should then investigate how the presented methods can be implemented in that framework. In order to achieve this, it is furthermore necessary to understand how analytic approaches of information generation can best be combined with experimental approaches. An investigation of the strategies that startups use to generate insights, such as the Lean Startup method, appears to be a starting point with good prospects.

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