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# Technological uncertainty and verification & validation activities

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**Abstract:** Product development decisions are a great management challenge, especially in turbulent business environment. Management is forced to make decisions before they have essential information on markets and technologies. This study analyses how ICT companies cope with uncertainty, and challenges, caused by the changing environment, focusing particularly on the role of verification and validation (V&V) activities. This article highlights that, when properly conducted, V&V can aid in providing required information, and helps in obtaining more profound understanding already during early part of product development. The study covers three company types: companies with products of their own, original equipment manufacturers, and subcontractors.

**Keywords:** Uncertainty; Product development; Innovation; Verification; Validation; Learning; Continuous improvement; Technology management.

## 1 Introduction

Top management needs information in order to make business decisions. The need for information and the importance of learning are amplified especially during technological innovation and new product development (NPD), involving both market and technological uncertainties. Technological uncertainty is a vital issue for companies, and influences product development (e.g. Magnusson et al., 2003; Magnusson and Berggren, 2001). Uncertainty can be understood as management's challenge relating to decision-making, when all the relevant information is not available (e.g. Song and Montoya-Weiss, 2001). Technological uncertainty is seen inherent characteristics in NPD, and is highlighted when advanced technology is involved (e.g. Song et al., 2007; Ax et al., 2008). Companies have to find methods to better manage uncertainty and learn from the experiences of previous projects, and other companies. Learning must, however, happen in an organised manner and be embedded into organisational memory (Wagner, 2003; Lee et al., 2008).

Research on uncertainty is twofold, where some of the research concentrates on external factors, such as market and technology forecasting, in order to clarify development trends (e.g. Salomo et al., 2007; Calantone et al., 2003; Childerhouse and Towill, 2004; Borjesson et al., 2006; Backman et al., 2007). Others consider uncertainty unavoidable due to the discontinuities caused by disruptive technologies. The latter pay attention on issues companies can utilise to react flexibly, and emphasise improving their internal NPD processes to better address the uncertainties (e.g. Meyer and Lehnerd, 1997; Suh et al., 2007; Robeson and O'Connor, 2007; Varela and Benito, 2005; Massey and Kyriazis, 2007).

Especially in the information and communications technology (ICT) sector, technological development has resulted in complex products, and offers virtually indefinite number of features. Increased complexity has caused difficulties in designing and producing electronics products defect-free (e.g. Woodward and Hennell, 2005; Black, 2004), and verification and validation (V&V) activities have hence become increasingly significant for development. *Verification* is widely understood as a method to prove compliance with specifications, using methods, such as inspection, demonstration, analysis, and testing (e.g. Perttula, 2007; Mooz et al., 2003). *Validation* has an aim to assure that the user will be satisfied (e.g. Huber, 1999; Dore et al., 2007). V&V is estimated to take 30 to 80 percent of total high-tech product development resources (e.g. Engel & Last, 2007; Gilb, 2005; Runeson et al., 2003; Murray, 2007). V&V can be seen as an effective means for learning and thus reducing uncertainty.

The above mentioned is the motivation for considering how organisations cope with uncertainties in their NPD. The study also considers how ICT companies utilise V&V activities for tackling these uncertainties. The study analyses differences among three company categories: independent actors with products of their own, original equipment manufacturers (OEM), and subcontractors. The research objective can be condensed into the following research questions:

**RQ1** How do different approaches aid addressing uncertainty in high tech NPD?

**RQ2** How are different types of companies coping with uncertainty in high tech NPD, and how can V&V aid efficient NPD and continuous improvement?

## 2 Managing technological uncertainty

Technological uncertainty together with market and revenue uncertainties is a seen as a challenge for decision-making (e.g. Sengupta, 2005; Chen et al., 2006; Murto, 2007). Technological development is seen to influence also markets, and is not only an internal NPD issue (Gressgard and Stensaker, 2006). Different methods are considered in the literature as means for coping with technological uncertainty, including; simultaneous development, project portfolio management, platforms, and verification and validation. (e.g. Chen et al., 2005; Lakemond and Berggren, 2006; Bstieler, 2005). Project portfolio management probably is among the most unambiguous way to describe and manage technological uncertainty. Also, commonly discussed product development funnel has been developed further to address this ambiguity. (e.g. Feland et al., 2004; Matthews, 1991; Wheelwright and Clark, 1992a; Wang et al., 2008; Zhang and Doll, 2001).

### *2.1 Simultaneous technological alternatives during product development*

Traditional design practices aim to obtain a solution quickly, and later modify it until the objectives are met. This approach is also called 'point-based' product development, where the initial choices determine success (e.g. Joglekar and Rosenthal, 2003; Zhang et al., 2002; Zhang et al., 2008).

Conventionally decision-making in NPD is based on schedules, as the phase review models, and similar methods suggest (e.g. McGrath 1996; McGrath, 2004). Whereas, companies, such as Toyota aim to solve problems continuously based on available information, instead of fixed date milestones (e.g. Morgan and Liker, 2006). This type of just-in-time decision making utilises an information-based approach, opposed to schedule-based approach, and decisions are made when all necessary information is available. Decisions can thus be made earlier than artificial decision gates, preventing wasting time, or later when there is not enough information available to make an optimal decision. (e.g. Holman, 2003; Perttula, 2005; Laurindo and de Carvalho, 2005; Moultrie et al., 2007).

There are different models that address gradual selection from a large pool of alternatives. The models include funnel and 'set-based' approaches (e.g. Cooper, 2008; Wheelwright and Clark, 1992a; Liker et al., 1996; Yassine et al., 2008; Drejer, 2008). These approaches help coping with uncertainty by delaying final decision-making. For example, Ford and Sobek (2005) point out how longer time spent in early NPD enables organisations to have more alternatives and potentially better solutions later.

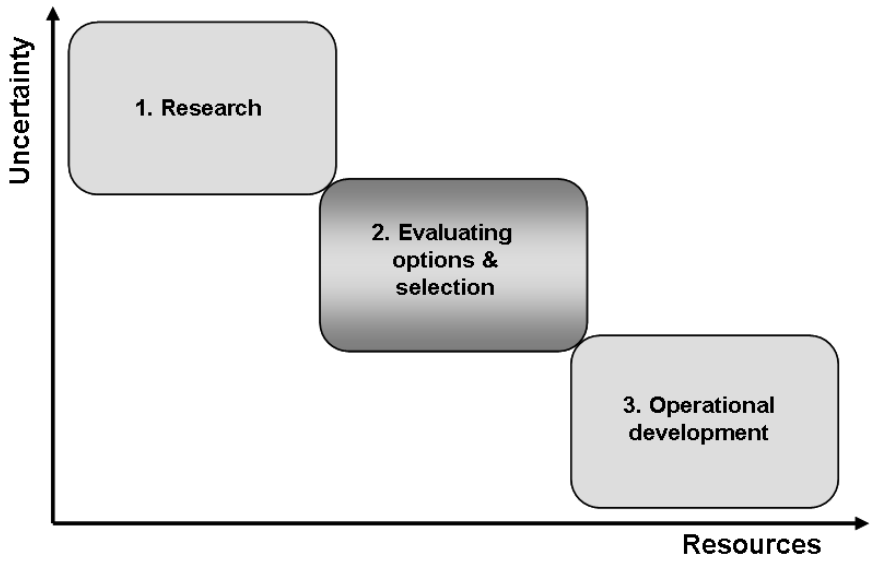
Set-based product conceptualisation has been highlighted as an important issue for flexible management of NPD, enabling multiple options, and timely feedback (e.g. Ford and Sobek, 2005; Zhang et al., 2008; Hines et al., 2006). These types of approaches allow companies to anticipate changes, and swiftly facilitate operational manoeuvrability. These needs for adjustments are typically caused by altered customer requirements, technical, or engineering problems. Set-based approach allows offering a variety of products with reasonable costs. The use of this virtually inefficient approach has made, for example, Toyota's development fastest in its sector (e.g. Morgan and Liker, 2006).

### *2.2 Project portfolio management and technological uncertainty*

Coping with uncertainty can also be considered from the viewpoint of project portfolio management, instead of a single project's perspective. Research and development (R&D) projects can be categorised into three different groups based on allocated resources and uncertainty (see Figure 1). Long-term research for developing future technologies forms

the first group. The degree of uncertainty is high, and the projects are seen as compulsory overhead costs needed to secure future success. The purpose of the second group is to evaluate technologies and reduce associated uncertainty, and finally to select the most potential ones. The projects of the third group are seen as investments, while the markets and the development and manufacturing costs are known well enough to calculate return on investment. The degree of uncertainty is low at this stage. The portfolio management encourages companies to initiate second-group projects, with a sole purpose to decrease uncertainty before committing into large scale development projects. (Matthews, 1991; Suikki, 2007; Suomala and Jokioinen, 2003; Suomala, 2004)

**Figure 1**. Project portfolio management




## *2.3 Platform development*

Platform development is a significant R&D tool, and can be considered as a means to cope with uncertainty during NPD (Gershenson et al., 2003; Zhang and Doll, 2001; Robertson and Ulrich, 1998; Salonen et al., 2008; Meyer and Utterback, 1993). Platforms are often considered broadly as a planning construct instead of addressing the needs of a single product (e.g. Yang and Jiang, 2006). Platforms are seen as the basic structure with a common set of components, modules, and parts from which derivate products can be generated, while maintaining the core technology (e.g. Yakob and Tell, 2007; Meyer and Lehnerd, 1997; Koufteros et al., 2005; Lee, 2007). This approach reduces the time used for new product planning, while useful elements already exist (e.g. Robertson and Ulrich, 1998; Kim et al., 2005). Technical and marketing uncertainties are lower, and product changes can be made more rapidly (e.g. Koufteros et al., 2005). Tailoring for customer needs can be conducted fairly late during the development process when utilising platforms (e.g. Ratamaki, 2004). However, platforms can fail in many ways as they can be complicated to design (e.g. Robertson and Ulrich, 1998; Wheelwright and Clark, 1992b).

## *2.4 Verification & validation and NPD uncertainty*

Verification and validation is an effective way for collecting information, and thus reducing uncertainty. However, conventional pass/fail type of V&V for checking whether requirements are met or not does not increase deeper understanding. In addition, V&V is typically considered too late in the development (e.g. Perttula, 2005; Harkonen et al., 2009; Hsieh and Chen, 2005; Belt et al., 2008; Host and Johansson, 2000; Mahanti and Antony, 2006). In practice, errors and misunderstood requirements are more expensive to fix the later they are addressed (e.g. Boehm, 1981; Chun, 2006; Butcher et al., 2002; Firesmith, 2007).

Perttula (2005) has introduced an information-based approach, which is especially beneficial for a situation with changing requirements. In this approach more information is collected from the product during V&V, than is necessary for pass/fail decisions. When requirements later change, it is possible to come back to the information collected earlier, to confirm whether the product meets the new requirements, without repeating the physical tests. This '*understanding enhancing V&V*' (UE V&V), or set-based verification as Perttula (2007) calls it, strongly relates to the methods utilised by for example Toyota, where all the relevant information of a design is attempted to collect during early NPD. UE V&V include methods, such as simulation, modelling, measuring, analysis, and ijiwaru testing (e.g. Morgan and Liker, 2006; Fan and Yu, 2004). It is then possible to refer to this information when requirements change. This is one of the reasons why UE V&V approach is beneficial for situations with high uncertainty.

Modern gadgets typically include both software and hardware. Performance of a product, or its component, is the determining factor, not whether this is achieved through hardware of software. The significance of understanding enhancing type V&V is highlighted in module/ platform NPD enabling later reuse without carrying out re-tests (e.g. Perttula, 2007).

Typically, the requirements are stabilising during the NPD process and the role of V&V changes. Pass/fail verification is more effective during later stages, when uncertainty diminishes and efficient execution is crucial. (e.g. Ebert, 2007; Beecham et al., 2005).

## *2.5 Synthesis on managing technological uncertainty*

The different viewpoints on managing technological uncertainty in high tech NPD have been summarised in Table 1. This synthesis highlights the key findings from the theory for the purpose of this study. The scope of this summary was to form an adequate basis for conducting the empirical study, as presented later, rather than to list all the possible methods to cope with technological uncertainty.

**Table 1** Synthesis on managing technological uncertainty.

| **Developing simultaneous alternatives** |
|---|
| Developing, and studying, simultaneous alternatives reduce risks, and aids in gaining understanding.<br>Enables choosing several directions, and reacting to changes.<br>Enables delayed decision making.<br>Requires resources and time. |
| **Project portfolio management** |
| Promotes the establishment of projects for strategic options that have a goal of better clarifying few technological alternatives for increased understanding. |

| |
|---|
| Categorises R&D projects in two dimensions of uncertainty and resources.<br>Requires resources and time. |
| **Platform development** |
| Solutions that have once been sufficiently considered can be later utilised for a number of purposes.<br>Enables rapid moves, using existing building blocks.<br>Final decisions can be delayed.<br>Not always the most customer oriented approach.<br>Can be complicated to design<br>Requires resources and time when platforms are developed. |
| **Understanding enhancing V&V** |
| A set of methods, assisting to enhance understanding, especially during early development.<br>Accelerates, and clarifies activities towards the end of NPD process.<br>Significance for platform based product development enabling effective reuse<br>Requires resources and time during the early NPD. |

## 3 Research process

The empirical study was conducted to better understand how ICT companies cope with technological uncertainty. The study covered methods of developing simultaneous alternatives, project portfolio management, platform development, and understanding enhancing V&V. The empirical study consisted of fifty interviews, comprising a representation from different phases of the product development process. Interviews were conducted informally, allowing the interviewees to explain and clarify the cases and topics as entities. The participants interviewed were chosen on the basis of their professional background and expertise. Selected interviewees hold responsible positions in the companies, ensuring up-to-date knowledge and high motivation towards the discussed issues. The individual interview results were separately analysed for three different company categories, namely independent actors with own products, original equipment manufacturers (OEM), and subcontractors.

*Independent actors* have products of their own, and they do not have dominant, single customers influencing their business. They typically invest themselves in the follow-up, analysis of technological development, and into measures for decreasing the associated technological uncertainty. *OEM*s typically cannot choose all technological alternatives freely as the role of the customers is dominant. For example, the external interfaces are typically defined by the customers. OEMs invest significantly in improving internal processes and production technologies. However, they can influence the technical properties of their own products, and thus also invest in developing new technologies. *Subcontractors* can influence product technologies only partially, as they are typically defined by their customers. These companies concentrate on improving internal processes and production technologies.

The interviewed companies provide products for both business-to-customer (B2C), and business-to-business (B2B) markets. Some of the companies have business relationships with each other, and products of some companies are inputs for others. Therefore, these interviews represent uncertainty and V&V activities in a versatile manner and provide understanding of managing diverse issues.

Examples of interviewee comments are presented in the Appendix. The analysis of the interviews is presented in the section *4. Results*.

## 4 Results

### *4.1 Independent actors with own products*

Company size seems to play an important role determining to a great extent, how the particular company addresses technological uncertainty. The smaller the company, the less methods are used. The largest and the most advanced of these companies utilise all the analysed methods for addressing technological uncertainties. B2C companies tend to utilise the development of simultaneous alternatives more, as they cannot be sure of the future purchasing decisions of their customers. In contrast, system developers that are in the B2B business, utilise the simultaneous development less, and rather follow the relevant standards and the desires of their customers. The main rule seem to be; the greater the uncertainty the more simultaneous development.

Simultaneous development is utilised only for technology, or platform level development, yet product development is mainly executed by utilising only one option. Different types of back-up alternatives are also considered quite often. Nevertheless, in small companies parallel solutions were practically non-existent. Larger companies have separate research centres for the early part of the development chain, and are thus capable of studying a large number of initial technological options. Those technologies that are most suitable for platforms, and product projects, are selected.

All the studies firms utilise platforms in their NPD. The larger companies emphasise the importance of technology platforms over product platforms. Platforms are seen to ease the pressure on verification and validation activities, shifting the focus onto interfaces. However, in practice platforms are a challenge for V&V activities, as according to the interviewees, too often they are taken into product development before they are properly tested and finalised.

The categorisation of R&D projects according to the associated uncertainty, and allocated resources is not a familiar issue to the managers of this business sector, but are addressed in other ways. The level of uncertainty is seen to determine the number of parallel alternatives. Feasibility studies are typically conducted prior to committing significant resources.

According to the interviews the companies in this category use UE V&V in the early part of NPD, at least to some extent. In the latter part of NPD pass/fail V&V is utilised to check whether requirements are met or not. Currently, V&V activities are seen to have a greater emphasis in the latter part of the development chain, and pass/fail V&V is dominating.

Nevertheless, V&V activities, in the interviewed companies, are also seen to include other methods, not only pass/fail testing. This is to address the needs of technology development. UE V&V is seen to support simultaneous development by giving broader information in the early part of NPD.

In addition to the methods described in the research process, companies of this category highlighted methods of standardisation, prototyping, and forecasting / roadmapping, as potential means for addressing uncertainty. Standardisation is utilised commonly. Critical issues, such as interfaces, are among the first to be standardised. Larger and more developed companies are strongly engaged in the development of new standards for the business sector. As a consequence, they will have prior knowledge when new solutions are available. Once technology suppliers start offering these new solutions the larger companies are ready to utilise them efficiently. Standards have a strong influence on product requirements, and early involvement in standardisation enables companies to consider V&V issues earlier.

Prototyping is seen as a means for studying the subject under development in a tangible manner, and to learn from a new technology. Prototypes are also used together with pilot customers to check whether a product meets their needs.

Companies in this category systematically utilise technology forecasting and roadmapping. Cooperation with research institutes and universities is extensive, and the loop from vendors is seamless especially in product technologies. Descriptive scenarios for business and technology environments are developed in parallel. Larger firms define the most important technology fields and follow them closely. Technology forecasting in smaller firms of this category, seems to be shallow, and they are forced into a follower strategy. The larger ones, on the other hand, are typically capable of being at the pinnacle of technological development.

### *4.2 OEMs*

According to the interviewees, companies of this category typically do not develop simultaneous technological solutions. Back-ups are, however, considered. Company size, nevertheless, plays an important role in the extent of simultaneous development. The interviewed companies direct the majority of their resources into operational product projects. Only a small share of resources is allocated for research projects or for creating strategic options. All the interviewed companies base their products on platforms to a great extent.

The companies in this category have technology development of their own as a consequence also they utilise UE V&V in the early part of NPD, but not as broadly and as systematically as the independent actors.

In addition, according to the interviewees, OEMs cooperate with research institutes and other companies, and can thus obtain information on technological developments. In addition, the companies follow the development of patents and standards. These companies strive for close cooperation with their customers in order to have prior knowledge on technologies to be utilised in the future.

### *4.3 Subcontractors*

Prior to making decisions on product development, these companies conduct feasibility studies in order to clarify the technologies new products should be based on. Developing simultaneous technological alternatives is practically non-existent. The role of sub-contractors is often to act as a resource base for their customers.

Subcontractors typically utilise platforms, while customers often decide technological platforms the work is based on. However, the interviewed subcontractors do also have modules and platforms of their own. Should a product developed for a customer project prove especially successful, subcontractors occasionally utilise these solutions in their own product platforms, and in some cases, offer them to other customers.

According to the interviewees, subcontractors concentrate their V&V activities on pass/fail testing to assure the compliance with customer requirements. In the case of subcontractors having products or platforms of their own, they have the responsibility for their development, and as a consequence UE V&V methods are occasionally utilised.

In addition to the methods described in the research process, companies in this category utilise technology forecasting and agile development methods to address technological uncertainty.

Technology forecasting in these companies is dependent on cooperation with their customers. In addition, these companies independently follow the development of technologies, critical for their own operations.

According to the interviewees the business environment is getting increasingly turbulent, and consequently, companies must have the ability to quickly react to any changes. The study includes several software companies, who adopt agile methods to address this challenge, allowing them to obtain further information and feedback already during NPD. Features are developed and even launched, in agile development, before the final products are completed.

### *4.4 Analysis of results*

The interviewed companies seem to comprehend the necessity of emphasising the early part of NPD. Customer needs and technological opportunities are clarified in the beginning of development projects, using for example roadmapping. Feasibility studies are used to decrease the uncertainty with technologies, prior to committing significant amount of resources.

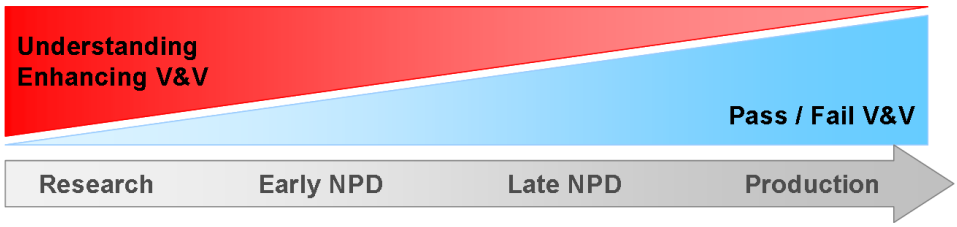
Most of the interviewed companies do not use the postponing of the final technological decisions, rather they tend to make the decisions as early as possible, opposed to the findings of the literature review.

The study showed that project portfolio management is utilised in most companies with products of their own. Only the most successful companies seem to utilise the principles of simultaneous development in practice. Companies in B2C business utilise more simultaneous development due to greater uncertainties in customer needs, than system manufacturers who operate in B2B environment. In addition, companies try to minimise the uncertainty in product development through participating in creation of business sector standards, and using platforms, prototyping and agile development methods.

Verification and validation activities are seen inherent to all the interviewed companies, but a deeper utilisation of V&V as a means for tackling uncertainty has not been internalised. In the early part of NPD, V&V are typically used finding the performance limits of the new technology, for example, through simulations and modelling. One of the studied companies gave a practical example on utilising simulation during early NPD instead of drop tests on final products. This enables addressing potential problems early, rationalising the entire NPD chain. The same logic applies for more complicated entities, including both hardware and software. From the viewpoint of system design, technological uncertainty decreases when the performance of single components and modules is better understood. By utilising UE V&V during component and module development, more insight is gained for system level development.

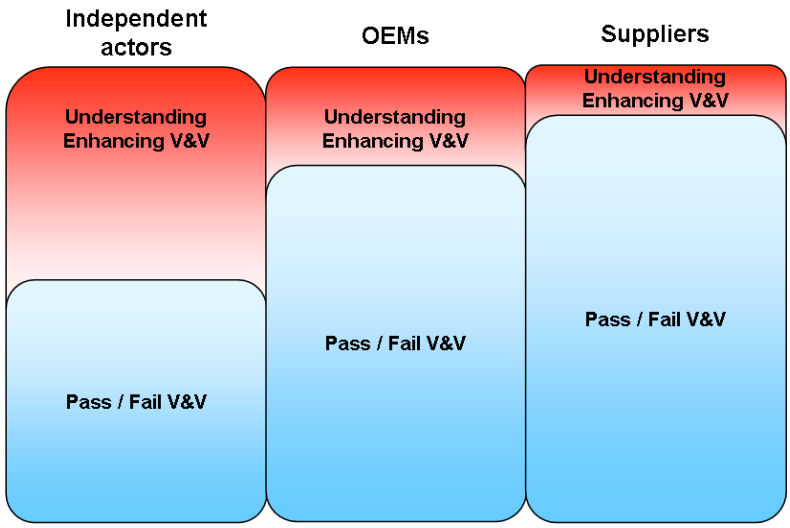
In the productisation phase V&V is seen to mean testing against requirements, V&V is thus of pass/fail type. During the productisation phase it is already known what to test and how, as the previous phases have generated the norms for V&V in order to create an acceptable product. Ideal division of V&V efforts between UE V&V, and pass/fail V&V is illustrated in Figure 2. Uncertainty is greatest in the beginning of NPD and UE V&V is more beneficial. Towards the end of NPD, relevant understanding exists and as a consequence uncertainty diminishes making pass/fail V&V sufficient and more efficient.

**Figure 2.** Ideal division of V&V efforts between understanding enhancing type, and pass/fail V&V




The three company categories proved to be clearly different in the way they handle V&V activities. *Independent actors* utilise UE V&V the most, and within the category, the most advanced companies utilise UE V&V more than smaller and less developed ones. *OEM*s utilise UE V&V, but significantly less than large advanced companies with products of their own. In the *subcontractors*' category, V&V typically means pass/fail testing as the requirements are set by their customers. UE V&V is utilised by subcontractors only when they develop platforms of their own. Figure 3 summarises the relative divisions of the two types of V&V efforts among the studied company categories.

**Figure 3.** Relative divisions of UE V&V and pass/fail V&V in the studied categories




## 5 Conclusions

Companies are constantly living in a turbulent business environment with market and technological uncertainties. As a consequence, requirements typically change during the NPD process, causing challenges. Despite of these uncertainties, companies are forced to strive for continuous improvement. There is a need to learn from previous projects and other companies in order to enhance technological innovation.

The study showed that different methods are utilised to cope with uncertainty in high tech NPD process. Simultaneous development, project portfolio management, platform development, understanding enhancing V&V, agile methods, prototyping, and standardisation are among the methods companies use to address uncertainty. All the methods, discussed in this study, have two common nominators, enhancement of

information during early NPD, and intentionally building options for the management to have choices for later NPD. Both of these allow companies to make their final technological decisions later when they have more information and deeper understanding.

All the interviewed companies are using all the studied methods to at least some extent for addressing uncertainty, but also other methods are utilised. However, simultaneous development, apart from in a back-up sense, is systematically applied only by the largest and most developed companies. Companies with products of their own tend to use a larger variety of different methods than subcontractors, OEMs being an intermediate of these two.

Verification and validation is typically emphasised towards the end of the NPD process, and is of pass/fail type. The more successful companies, with products of their own, utilise understanding enhancing V&V methods during the early NPD, but the deeper understanding of their full potential varies. However, also OEMs and subcontractors utilise UE V&V methods, but to a lesser extent, and less systematically. A rule of thumb seems to be that larger companies use more of these methods, than smaller ones, and subcontractors use them the least.

Technological uncertainty is inherent in new product development. Different types of companies face different challenges in addressing uncertainty. Independent actors, especially B2C companies face directly the impacts of changing customer requirements stronger than system manufacturers operating in B2B environment. Subcontractors do not have technological uncertainty in the same scale, as their customers have a more influential role. Relying too much on customers, may however be a risk, in the form of the customer demanding a new type of know-how at some point.

This study indicated that ICT companies tend to make the technological decisions as early as possible leading to great technological uncertainty. Should the initial decisions prove wrong, significant costs are created in form of wasted resources and delayed development. Maximisation of understanding in the early part of NPD allows companies reacting to surprises when requirements change, without entering a panic mode, or causing excessive delays. The inclination of companies to make decision early is due to the mindset dominated by the schedule-based view on NPD, whereas the management should consider more information-based approaches. Decisions should be made when required information is available, not based on pre-set schedules. The challenge is accumulated, as the studied companies are typically more technology, than business oriented.

A central finding in this study was the potential of UE V&V for addressing uncertainty in NPD. It can also facilitate deeper learning from the possibilities and limitations of technologies. UE V&V methods suit for the purposes of hardware and embedded products, not necessarily pure software code. Currently, the utilisation of V&V for enhancing understanding is not sufficient. Building adequate understanding is, however, vital for continuous improvement. Even the most advanced companies should consider possibilities to increase the amount of UE V&V, and to shift the emphasis to earlier NPD. Especially smaller companies and OEMs could learn from the experience of more successful ones. However, it is not necessarily beneficial for subcontractors to significantly increase the amount of UE V&V. Nevertheless, it might be worthwhile to analyse the issue from their customers' standpoint, as understanding customer behaviour is always essential. In the case of product development cooperation, a client can attempt to build UE V&V into the contract, should they find it desirable.

This study was conducted to gain new understanding on the current level of coping with uncertainty, and how V&V can ease the situation. The study especially emphasised the role of V&V for addressing uncertainty, and its relationship to a collection of other methods. It was not meant to cover all the potential ways of addressing uncertainty, and therefore should an extended study be conducted the results may be slightly different.

The interview part of the study analysed whether the chosen methods are in use in ICT companies, but a more profound clarification of utilising these methods was outside the scope of this study.

Only the more advanced companies utilise UE V&V systematically, and studying these companies in more detail is a potential topic for further research to gain a deeper insight. Additional research is also required to clarify how to find a balance between the benefits of all the used methods, and cost control. In addition, the differences between incremental and radical innovations, in addressing uncertainty, might be an issue worth further study. It would be sensible to conduct a statistical analysis for a larger set of companies to clarify the numerical distribution of the methods used for coping with uncertainty.

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## Appendix

### *Examples of the interviewee comments*

| **Independent actors with own products** |
|---|
| Simultaneous development |
| "Technology is frozen about half a year prior to it having to be ready. In practice, however, technology is never frozen, meaning that the product can always opt to change its mind, should there be any urgent motives."<br>"In software development, the results of our work are primarily released twice a year, in so called productisation branches."<br>"In the product phase we do not consider alternatives, but when starting the development of a platform, product family, or configuration, we do have multiple alternatives, at least when specifying the development."<br>"It is important to increase the number of ideas in the beginning of the funnel."<br>"Our corporate research centre does corporate level blue sky research, where our role is to conduct applied research, potentially leading into developing products, or technologies related to products. However, we occasionally develop technologies straight into products."<br>"Simultaneous development is not conducted during the productisation, as we do not have resources for that. Technologies are attempted to freeze in pre-research phase."<br>"Several alternatives are not developed simultaneously. The concept may, however, change during the development, for example when the customer requirements change, or a revolutionary new technology emerges in the market."<br>"The rule of thumb is that should the risk be great, multiple options are developed, and when the risk a less dominating factor, a single solution is developed."<br>"One or two back up concepts are created until the new technology is functional and reliable enough."<br>"Not in a classical sense as for example Samsung, but it is a fact that a product concept does not live freely until the end. We do not have teams competing for something and select the better result." |
| Platform development |
| "Our activities are platform based, they are used for as many products as possible. Variations are created through configurations."<br>"Nowadays, we emphasise technology platforms over product platforms."<br>"Platforms are increasingly utilised. Evolutionary platform development enables extremely rapid product development. Once we need a tool, the development is really only connecting Lego-blocks and pushing it to the market within days."<br>"Roughly 95% of our products are platform based." |
| Project portfolio management |
| "We do evaluate the relation of uncertainties and resources."<br>"We do not conduct simultaneous development during productisation, but the risk is calculated with prior studies."<br>"A feasibility study is conducted prior to allocating resources for developing a product. Usually the available technologies are compared and chosen for the project." |

*Technological uncertainty and verification & validation activities*

"The main rule is that the risk will influence the number of alternatives to be developed, higher risk means that more options are considered."

Verification and Validation

"V&V at the early product development is mainly exploring the limitations, a learning curve"
"V&V in early product development is verifying the requirements specifications and reviews, the results are utilised to create product specifications."
"In production, V&V assures the compatibility and the intended functioning of the product"
"Verification and validation, in applied research, aid in finding the limitations for the technology under development, and to understand economic feasibilities."
"Developing measurement equipment, simulation, standardisation, reviews, obtaining knowledge, and development of devices and software, are utilised in applied research as means for reaching the set goals."
"During early product development, tested platforms, simulation results, and test results for components are expected. The goal is to have the required understanding on the capability of realising the planned product with the available technologies."
"At the end of the late product development, the product must comply with the set requirements, and be within error margins, ready for the markets, including verified hardware and software."
"V&V in our context means developing the product, so that it is both functional, and complies with the requirements of our customer and authorities."

Other methods

"Interfaces are attempted to standardise. We aim to agree upon, and standardise especially hardware interfaces. It is beneficial to have multiple manufacturers to follow same standards."
"We actively take part in standardisation, and push through the features we see necessary. Once a standard is set, the vendors start having the hardware that we can utilise. The way we work takes standardisation into account and allows adjusting our roadmaps."
"Standardised elements are convenient to use for critical parts as building blocks. We have aimed to standardise certain interfaces."
"Evaluating and forecasting technologies is systematic, with cooperation with research institutions, searching publications, utilising consultants, and such traditional commercial sources for observing trends."
"Technology fields (20-30. are defined, out of which their content is analysed for the current situation, and its development. Beside these fields, there are certain product technologies that are clarified together with our vendors to understand their view on the future."
"First we analyse our business environment outlook, and at the same time the technology environment outlook. These two are used to form some sort of presumptions for defining our technology strategy."
"One task of R&D process is to follow technologies. We have a keen eye on new and existing technologies and their development. We have a built in follow up procedures for the R&D personnel."

**OEMs**

Simultaneous development

"We can only use our own judgement on external technologies, when deciding the direction for our product. With internal technologies, we can experiment different possibilities. Simultaneous development would make sense, but our economic realities set some restrictions."
"Very little simultaneous development is utilised."
"Research work in the feasibility study phase cannot be overly heavy structured, before more money is invested. There can be some waste, thus once the project is started reversing is not an option anymore."
"A company of our size does not have the luxury of considering multiple options; we have to make a choice on a certain technology. In a risk management sense, we always consider the what if situations for technologies not working as planned. We have a back up plan."
"There are plenty of negotiations with the customers beforehand. That s where the information over the technologies to be used is given. Business units and product management are responsible over these issues."

Platform development

"Certain products are built on previous products, the core remains the same. We utilise platforms."

"Our products have a base architecture, on which functionalities are added in a flexible manner."

"On external technologies we can have our own estimate on where to go, but on internal technologies we can better try different possibilities."

Project portfolio management

"We can only have our own estimate on external technologies. With internal technologies we can experiment, and try different solutions. We have a strong emphasis on ROI projects."

"I m not familiar with the Matthews model, but we use models with similar elements. A majority of resources are directed for operational product development."

Verification and Validation

"Technology is often immature for production as component variation is no sufficiently considered during the product development."

"We are not learning enough from the previous examples as the projects tend to be unique, and we are lacking of systematic processes for V&V."

Other methods

"Knowledge is obtained through standardisation organisations (ETSI, 3GPP, WiMax forum, WRF, and so on.., and through close cooperation with our customers."

"The aim is to follow, and take part, in research programmes, where different technologies are studied. With universities, research institutes and other strategic research partners."

"We try to follow those technologies we believe the customers will require in the future."

"We study other companies patents."

"Strategic research programmes with our partners also aids technology forecasting"

"We are in a follower role with regards to all the standards. We are, however, increasingly utilising standards for developing our processes."

**Subcontractors**

Simultaneous development

"Primarily, any technology related product decisions are made by the customer."

"We sell test services, the customer will make the technological choices."

"A feasibility study is conducted in the beginning of a project to decide the technologies for a product. I do no remember a base-technology having been changed during a project."

"The company chooses to be active in the technologies which seem promising technologically and commercially."

Platform development

"We do utilise platforms to a great extent."

"Our software development is based on platform thinking."

"The company focuses on creating technology, re-usable components, solutions and competencies in-house."

Project portfolio management

"We do not use this type of thinking, but concentrate on the customer needs, and customer oriented solutions instead."

"In practice, we always operate in the last box of the model, as we do not make our own products."

Verification and Validation

"In early product development, verification and validation includes, testing against standards, platform development, simulations, testing the component characteristics."

"Our customer defines their own requirements, and technical specifications. We identify the requirements, and code them to trace them later."

"During the technology development phase, different standards (e.g. GSM, GPRS, EGPRS, WCDMA. are also studied to understand their influence on testing activities."

"During productisation, testing intends to find faults on the product under development, and to gain information on how to meet specifications."

Other methods

*Technological uncertainty and verification & validation activities*

"In the past years, we used to collect a huge number of functionalities into a single release in a certain interval. These days we utilise agile methods, such as scrum."
"Our customer is actively involved, from the very beginning, in the International standardisation work, when new technologies are developed. We are not active in standardisation ourselves."
"We take part in partner programmes of large companies. We follow, to what extent different technology bases are utilised."
"Customer decides the technology a product will be built on. We have the capability to jump onto a new technology base, should a customer wish to do so. This is why it is vital for us to see widely what s happening in the field."
"The aim is to forecast and follow technologies, and to see the direction they are going. Based on technical publications, discussions, communications with customers, postings and such. However, there is no systematic process."
"We consider the competences; one must have a clear view on what s coming. That s what is being analysed."
"Technologies are assessed and forecasted based on regular tracking, based on information from customers, partners and other actors in the eco system. Management meetings and reviews are held to define the technology and subsequent business roadmap."
"Agility is relevant for us, especially in market oriented software development. The aim is to react rapidly to arising issues."