TECHNOLOGY DEVELOPMENT PRACTICES IN INDUSTRY

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ABSTRACT
This article concerns technology development practices in industry. Its primary foci are on describing the technology development process, its management through normative models, and how technology is integrated and exploited through different platform approaches. The aim of the study has been to explore the external validity of previously acquired empirical results that have been obtained through a series of studies at Volvo AB, and in particular in the company context of Volvo Aero Corporation.

In order to meet our aim, we have chosen a multiple case study approach, involving four different companies. Results obtained in the different cases have been compared, and reflections have been made relative to what has been reported from earlier studies at Volvo Aero Corporation (VAC), and thereby indirectly to what can be found in literature.

What we can conclude is that most of the results previously obtained in VAC have also been found in the four companies included in this study. Apart from providing this answer to our research question, this article contributes empirical results from five different contextual settings concerning some aspects of technology development.

Keywords: technology development, stage-gate, and platform.

1 INTRODUCTION
The aim of this study has been to explore the external validity of empirical results that have been obtained through a series of descriptive and prescriptive studies at Volvo AB, and in particular in the company context of Volvo Aero Corporation (VAC), during the period 2006-2010 [1-7]. Primary foci have been on investigating the characteristics of technology development, applying the stage-gate model for such development and employing platform strategies for its exploitation.

The outline of the paper is that we relate the major findings from the first contextual setting (from Volvo Aero Corporation, in other words) and relevant literature concerning these results, followed by a description of our chosen research approach, obtained results, a discussion of our observations relative to previous results and, finally, we summarize our conclusions.

2 LITERATURE REVIEW
In the following paragraph, we summarize the results obtained in the different studies [1-7] with a short presentation of the results. We divide the review into three main paragraphs that indicate the topical focus of the different articles and summarize briefly some of the main references used in the different studies.

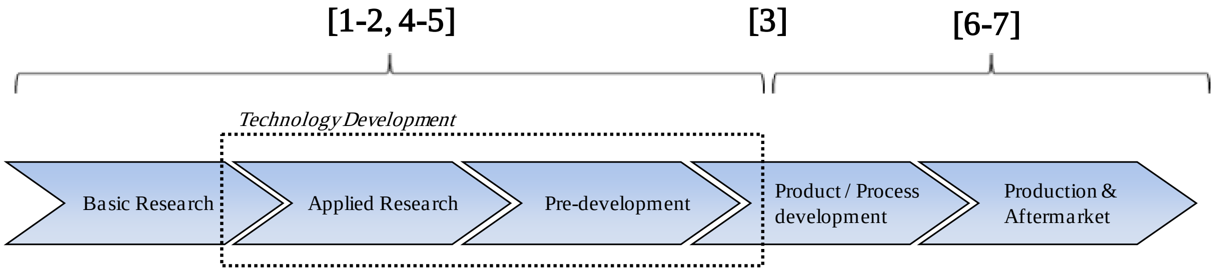

Figure 1. Position of the seven articles relative to the product life cycle stages.

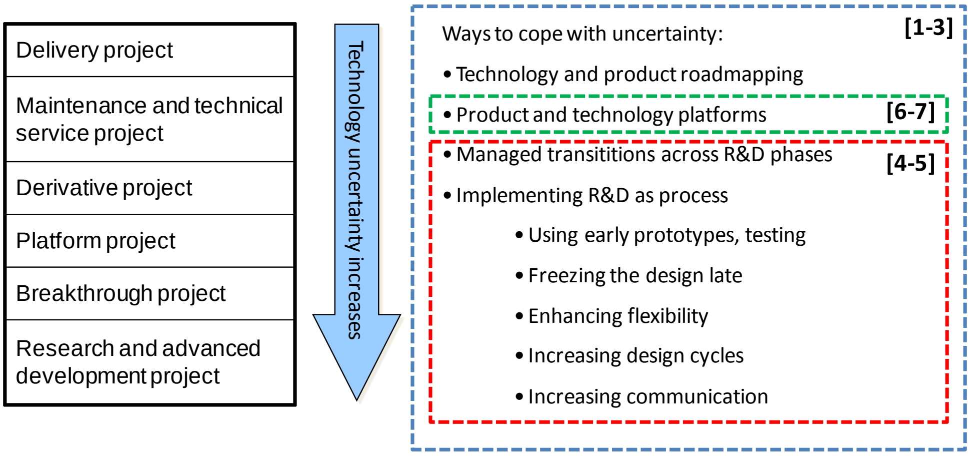

Figure 2. Position of the seven articles relative to the means of coping with uncertain projects, as proposed by Kähkönen et al. [8].

2.1 On technology and its process of development

Three of the studies aimed at understanding the technology development process, how the process is managed, and challenges therein. They are all descriptive.

"Technology management challenges for a sub-supplier in the aerospace industry" [1]

This was the first study in the series, and it broadly explored the process of technology development. Experience gained from the identification, selection, planning, execution and introduction of new technology was discussed with personnel from different functions in two separate product areas.

Main conclusions:

1. It was clear from both product areas that a well-formulated and well-communicated product plan or strategy has proven to be a vital guide for setting the direction of the technology development. However, due to the often very long lead times of developing and implementing new technology, it was also stressed that future needs not yet formulated or communicated by their customers had to be anticipated independently by the company.
2. To facilitate the implementation of new technology, it was believed important to consider early on in development how, when and where to apply new technology and involve stakeholders and users.
3. Since the technology development in a company tends to become incremental in specializations that are already fairly well-known, one has to make sure that the organization has the capability to generate and incorporate new kinds of knowledge.
4. The business model of the company and the long cycle times of aerospace products mean that the technology development efforts can be implemented at different phases of the product life cycle, rather than always going through all product development stages.

"The technology development process and its result – the case of Volvo Aero Corporation" [2]

Our aim in this study was to build better understanding regarding how new technology is developed in a corporate environment, and how this process can be described. This has been done through a retrospective study where the development of three innovations has been mapped, and where results have been compared to find similarities and differences.

Main conclusions:

1. It was concluded that a basic need, and a vision of a conceptual solution that meets this need, has defined and driven the technology development. The need for new technology is not fully known beforehand; rather, it evolves and grows into a need-solution tree in a highly iterative process. This need-solution tree changes shape as target applications shift and new needs are encountered. The validity of the technology tree is assessed and further developed relative to different potential applications. Through this exploration and development, a technology platform is built from which a series of different products can be generated. The conceptual solutions embody the vision and help in making knowledge gaps, potential risks, real problems and needs more concrete. The iterative process builds knowledge concerning the applicability of the technology, thereby mapping the bandwidth of the developed technology platform.

2. It has been shown that technology development can be seen as a series of iterative design activities where new technology is explored and developed in order to realize a basic conceptual vision. However, iteration, experimentation and learning are more emphasized during these early stages than what is normally acceptable when entering into dedicated product development.

"Requirements on New Technology and the Technology Implementation Process" [3]

This study focused on the later stages of technology development. The main research question was the following: *"What are the requirements on maturity of technology when this technology is about to enter into the product development process?"*. Requirements were explored and structured relative to six different technology categories (design solutions, materials, engineering methods, test and control methods, manufacturing processes, and manufacturing methods) from the perspective of three product development projects.

Main conclusions:

1. It was shown that requirements differed substantially when comparing the six categories, and also that the timing of mature technologies in relation to product design differed.
2. Furthermore, it was shown that attention should be paid not only to the capabilities of the technology as such, but also to how the organization builds new capabilities to implement and utilize the technologies. Approximately half of the identified requirements relate to aspects concerning the transfer of technology from applied research to implementation in the final application, indicating the organizational challenges in the transfer process.

2.2 On normative process models and technology development

In product development, the Stage-Gate model has been widely adopted, often with great success [9]. Based on this experience, many companies have chosen to implement similar models at the early technology development stages, something which has also been proposed by Ajamian and Koen [10] and Cooper [11], for example. However, there is a risk that by employing normative process models, one restricts creativity and the ability to explore [12]. Some researchers have argued that current practices of using the stage-gate approach are detrimental to explorative innovation involving a high degree of uncertainty [13, 14]. These conflicting propositions led us to conduct two studies concerning the application of the stage-gate model to technology development.

"Applying Stage-Gate Processes to Technology Development - Experience from Two Hardware-oriented Companies" [4]

This study aimed to answer the research question *"What is the experience from applying the stage-gate model to technology development in companies with operational differences, and what adaptations have been made to facilitate its usefulness?"*. Experience from two different companies was explored through a series of semi-structured interviews.

Main conclusions:

In the first company case (the aerospace case), the model had failed, while the model had proven successful in the second company case (the automotive case).

3. The adaptation of the model to technology development was one of the differences between the two company cases that had proven important for the success of the model. In the successful case, a dedicated model adapted to early development had been implemented, which was not the case in the aerospace company. The formulation in the automotive case considered the need for experimentation and exploration to a large extent, which was not equally apparent in the other case. Experience from both companies indicated that using the model when a certain degree of maturity had been reached was more successful, primarily due to the fact that goal formulation was more concrete and the route to follow better defined. The fact that the aerospace company had a larger amount of research projects, and thereby higher project uncertainty, may also explain the greater difficulties in a successful application of the model.
4. In the successful case, the model had been implemented in a consistent way throughout the company and was used in an identical manner irrespective of the particular development. Furthermore, the company had linked the model clearly to the different formal decision forums of the organisation. In the first company case, clarity regarding implementation and application of the model was not as apparent, and this contributed to the failure of the model.

"Technology development and normative process models" [5]

The aim of this article was to contribute experience gained from developing, implementing and using a version of the stage-gate model adapted to technology development. Additionally, a contribution was made as to how such a model can be used operationally. The model development and implementation was conducted at VAC and was a follow-on study to [4].

Main conclusions:

1. The concrete result from this action research study was a model, based on the NASA Technology Readiness Levels [15], to be used for technology development, primarily as a management tool. The model reflects the ambition to achieve a balance between management needs for simple, clear logic that is easy to explain and relate to and the developer's view of the need for extensive experimentation. Results from [2], showing that technology gradually expands in the maturation process into different sub-technologies with increasing levels of detail and concretization, had an impact on this mixed model. This is in particular reflected in the formulation of the gates and the recommendations regarding how to use the model in operations.
2. A first version of the normative process model has been tested in VAC. Preliminary results are positive, primarily through improved transparency in on-going activities and because actual status is clearly expressed and brought forward so that proper corrective actions can be made.

2.3 On the leveraging of technology through a platform strategy

Developing new technology is usually costly and time consuming, which is why there is interest in finding ways to exploit such investments efficiently. A platform approach may be one such strategy. Platforms have received extensive attention from the research community. Broad approaches have been proposed [16], as have modularized product platforms [17, 18] and process platforms [18]. Technology is often seen as a foundation that fuels platform formulation, but some authors discuss implementing technology platforms as a corporate strategy [19-21]. However, little research covers the application of platform development in a supplier and/or small batch production environment. This paragraph covers the results from two previous studies conducted in such a context.

"Platform strategies for a supplier in the aircraft engine industry" [6]

This study aimed to answer two research questions:

1. "*What current best practices on platform formulation could be applicable to a company like VAC, a sub-supplier in a low batch production environment?" and*
2. "*Based on the needs from a company such as VAC, how could a suitable platform be formulated?"*

Main conclusions:

1. This paper has shown that current platform theory is applicable to sub-supplier companies in the low volume high technology segment. However, formulating a product platform as one consisting of common modules or components is not seen as a fruitful strategy. The products are normally custom-designed for a particular application, primarily due to important design drivers such as minimizing mass or optimizing overall system performance. In addition, since VAC does not control the system architecture, there is always a risk of investing too much into methods and tools enabling design re-use connected to a specific architecture.
2. Based on our findings from VAC, we propose a platform strategy where a scalable product platform, based on product lines, and a technology platform, incorporating design and manufacturing knowledge, co-exist. The difference between the two platform descriptions is that the technology platform is not connected to a specific implementation, while the product platform is the application of that technology to a specific product family.

"Exploring the Potential of Applying a Platform Formulation at Supplier Level - The Case of Volvo Aero Corporation" [7]

In this study, the work initiated in the study described in [6] was continued. The potential for reuse in four different dimensions was explored through the following four research questions.

1. *"What is possible to reuse between similar products of different sizes?"*
2. *"What is possible to reuse between different generations of the same product?"*
3. *"What is possible to reuse from similar components offered to different customers?"*
4. *"What is possible to reuse between products with different applications?"*

The study was conducted at VAC. It retrospectively studied the reuse of elements within a particular product family and traced commonality between six different product developments.
Main conclusions:
The study showed that reusability exists mostly between different generations of products within the same family. However, to some extent reusability was also found between similar products in different sizes and between similar products offered to different customers. To a lower degree reusability exists between products with different applications, which also was the case regarding methods and technologies coming from other parts of the company and/or are applied on other types of products. Due to learning and modified customer requirements, the recurring elements have almost always been modified or altered along the way. Therefore, most reusability has occurred in the form of experience and lessons learned. The experience lies in the realization of the product, how to optimize it and how to obtain better quality. In summary, the study concluded that in a company like VAC, with low batch production and product designs driven by technical constraints (like weight and performance) and application specific optimization, a technology platform appears most promising.

2.4 The research question in this study

In each of the seven studies conducted, primarily in Volvo Aero Corporation, results have been obtained that have been discussed relative to available literature, thereby building external validity [22]. However, in order to investigate and possibly further strengthen the external validity of the previously obtained results, this study attempts to answer the following research question:
“Do obtained results from the unique context of Volvo, and especially that of Volvo Aero Corporation, apply more broadly in industry?”

3 RESEARCH APPROACH

In order to answer the main research question, we have chosen in this study to gather data through a multiple case study approach, involving four different companies. The chosen research approach, and the different steps taken in this study, are based primarily on recommendations from Yin [22].
The companies were chosen based on the fact that they are large with a global presence, are world leaders in their respective specializations, and have demonstrated resilience and the capability of sustainable innovation over many years. Three of the companies have their headquarters in Sweden. The exception is company D, which is part of a group of companies with headquarters in the USA.
Company A (automotive industry) has a role as system architect and integrator, which means that they control the interfaces and the requirements on the different sub-system levels. Business is done as B2B. The interviewees represent different parts of the organization.
Company B (paper products) develops, produces and markets personal care products, tissue, packaging, publication papers and solid-wood products. Business is conducted both as B2B and B2C, even though B2C normally is conducted through retailers. The interviewees come from a part of the Global Hygiene Category and represent product development, production development and research.
Company C (sub-system supplier) delivers products, solutions and services incorporated as components or sub-systems in many different types of mechanical systems. Business is conducted as B2B. The interviewees all come from a central unit developing production solutions for the different companies in the group.
Company D (sub-system supplier) is a diversified global manufacturing and technology company. They offer a wide range of products and services in the areas of network power, process management, industrial automation, climate technologies, and tools and storage businesses. The interviewees come from a company in the Group that develops, manufactures, and services, level measurement and control technologies for tanks. Business is conducted as B2B.
There are differences between the cases, e.g. regarding types of products (automotive/paper /mechanical/electrical), customers (few/many, B2B/B2C), and positions in industry (component supplier/system integrator). Similarities found when comparing the different cases will serve to build external validity through replication [22]. Differences in results will be discussed based on the differences between the four cases and the VAC case, and will add to the richness of the results.
Several different sources for data gathering were used, which is typical of case study research [23]. However, the primary method chosen was individual semi-structured interviews. Three individuals were interviewed from each company case, with the exception of Case C, where two interviews were conducted. The interviewees were all selected based on their expected ability to contribute to the study

topic. A summary of the position of the different interviewees from the different companies is summarized in Table 1 below. All interviews were recorded and transcribed.

Table 1. Positions of the interviewees in the four company cases.

Case	Positions of interviewees
A	Head of Research, Head of Material Development, and Head of Advanced Engineering Electrical Systems.
B	Head of Research, Product Development Manager, and Process Development Manager.
C	R&D Director and Program Manager.
D	Director of Engineering, Head of Development for Marine Applications, and Manager of Advanced Engineering.

Answers from the semi-structured interviews were linked to the different questions posed in the interviews. In the next step, the answers in the four company cases were analyzed and compared within the four company settings, and similarities and differences between individual interviews were examined. The step after that was to compare the answers from the four companies with the results from Volvo and analyse similarities and differences between the different cases.

When judging the trustworthiness of the results from the work, a number of aspects have to be considered. Yin (2003) distinguishes between construct validity, external validity and reliability for descriptive case studies. *Construct validity* has been addressed in several ways: the use of four separate cases, the use of multiple sources of evidence in each case, the review of partial results from key informants, the involvement of two researchers, and the logic and structure of the research, both in data collection and analysis. *External validity* has been addressed by comparing findings with results reported in literature and through the replication of results between the four company cases and the VAC case. Finally, *reliability* has been considered by documenting the different steps taken during the research. Examples of steps taken include written questionnaires used in interviews, recorded and transcribed semi-structured interviews, the storage of reviewed company documentation, and written documentation describing the different steps taken and results found in data analysis.

4 RESULTS

When presenting the empirical results below, we have used the same structure as in Paragraph 2. This means that we present the results relative to the conclusions from the different papers using the same numbering. This is done to make it easier to compare the results from VAC with the results from the four case companies in this study.

4.1 On technology and its process of development

"Technology management challenges for a sub-supplier in the aerospace industry" [1]

1. In all companies, most of the ideas on technology development come from the engineering organization. In reality, Product Planning plays a minor role, if any role at all, in defining long-term research initiatives. In the early stages, technology and societal trends, for example, are comparatively more important for setting priorities and direction. At later stages of development, Product Planning plays a more prominent role. Efforts are being made, to improve on pro-active product planning, but the realistic time perspective is rarely longer than 3-5 years into the future. Longer time horizons than that, as a tool to guide technology development, are not considered realistic. To ensure that technology development meets real needs, all the companies place considerable effort on communicating, discussing and balancing different efforts, both long and short term, throughout the development and adjust the direction if needed.
2. In all the companies, the application of the technology is usually a part of development from the very start. A real need has to be formulated; otherwise, the idea will never be pursued. Furthermore, all companies put considerable effort into having the end users involved to some degree in the development. As was stated above, the internal dialogue throughout the development is emphasized in all cases as vital for the success of the end result.
3. Most technology development in the companies is of an incremental character, but they are well aware that a balance between incremental and radical development is needed to stay competitive. Different measures have been taken in the companies to realize this balance. Company D, for

example, uses an approach originally proposed by Wheelwright and Clark [24] in which the incremental-radical balance of the project portfolio is regularly assessed by top-management.

4. This conclusion is not clearly supported by companies A and D. The reason may be that the interviewees in these companies primarily represent a part of the organization that focuses on developing new product functionality or improving product properties. Little or no effort is spent in this part of the organization on the production aspects, for example. The interviewees from companies B and C included representatives from the production departments. In these cases it was clear that implementation could go through new product development but was not restricted to that. It could be implemented directly into the production system, for example.

"The technology development process and its result – the case of Volvo Aero Corporation" [2]

1. In all the companies, a basic need drives technology development forward. Very little evidence, if any, has been found of technology development driven exclusively by curiosity or to build knowledge. In company A, one of the interviewees stated clearly that technology development motivated purely as "building knowledge" would never be accepted. Needs were found to change in all the companies during the course of development. The growth of the technology tree in the iterative process found in VAC was confirmed in all the companies. However, too much drift in needs/requirements was deemed negative, usually resulting in increasing costs and delays. Different strategies for balancing the explorative iteration with the need to deliver results that could be implemented were used. One of the interviewees in company B stated that if the basic driver changes, say, for example, from "product performance to product cost", it is usually better to stop the project and redefine it.
2. All the companies stated that a common delivery from technology development often is a conceptual solution to a need where its feasibility has been proven through testing. All the companies stated that, at the point when a decision on implementation should be made, there should be evidence that the remaining risk is acceptably low. The technologies needed to realize the concept are an important part of the "concept delivery". Methods utilized in product development are also used in these early stages, though often in a simplified state.

"Requirements on New Technology and the Technology Implementation Process" [3]

1. Several of the interviewees expressed that the delivery from technology development could not be expressed in generic terms but rather was defined by what was developed and its objective. The level of the technology varies significantly as well. It does not necessarily have to be a complete system solution. Examples of what the technology could be include the following: a new manufacturing process to be implemented in an existing machine, a modified heat treatment cycle for a particular material and application, a business case assessment of the technology, and a report with an evaluation of the technology and the potential benefits/drawbacks. The range is very wide. Still, a set of generic deliverables has usually been defined. This is further described in the following paragraph discussing the implementation of stage-gate models.
2. Extensive effort was made in all the companies to get "buy-in" from the major stakeholders as early as possible. This was done in order to ensure that the right technology was developed and also to get a pull effect from the receiving organizations. In all the company cases, personnel developing the technology also participated in the first implementation. Company A even had a strategy to include people as part of the "technology delivery" to the implementing organization.

4.2 On normative process models and technology development

"Applying Stage-Gate Processes to Technology Development - Experience from Two Hardware-oriented Companies" [4]

All the companies use some form of the Stage-Gate model during technology development. The level of detail, formalism, and adaptation to technology development differ however.

1. In companies A, B, and C, models adapted to technology development are used. A description of the different models is given in the next paragraph. All the models implemented have been adapted to the need for experimentation found in uncertain development. In all the companies, reiteration in the stage-gate, redirection, redefinition or cancellation of development initiatives is generally seen as something natural that happens in these uncertain phases, and not something

abnormal. It is seen as a consequence of the learning that is an important outcome from the different projects and that cannot be fully predicted.

2. All the companies used the same generic stage-gate model adapted to technology development on all their projects during this phase. However, quite a lot of room was left to make adaptations depending on the nature of each individual project. Furthermore, the decision structure was very clear in all cases, as was the link to the stage-gate model. What was apparent from the interviews was that the decision process in the companies is quite complex, with many different stakeholders more or less involved. Most of the interviewees emphasized that the open dialogue in the organization was important in order to build “a sense of urgency”.

“Technology development and normative process models” [5]

We provide below a short description of the different stage-gate models implemented in the four companies.

Company A classifies its development projects in three categories, Yellow projects, Green projects and Red projects. The Yellow projects are those activities covering the phases of Research, Advanced Engineering, and Pre-development. A defined five-stage model is used covering Research and Advanced Engineering, where generic goals, activities and deliveries from the different stages have been defined. For each gate, a check list has been formulated that is adapted to meet the needs of each individual development. At the interface between AE and Pre-development, a proven design concept should be available and customer benefit should have been identified. However, that benefit need not necessarily have been quantitatively verified, something seen as a part of the Pre-development stage.

Company B classifies its development projects in three different categories, Explorative Development Projects (EDP), Product Development Projects (PDP), and Product Launch Projects (PLP), which follow in sequence. For all three categories, adapted versions of the stage-gate model are used. The formalism of the process increases when passing the various phases, EDP-PDP-PLP. During EDP, the implemented model is less formal and involves more adaptation to the individual developments. EDP projects deliver one or more concepts with feasibility and risk reduction proven through test. These concepts are the starting point for the PDP project that may follow, if so decided in the organization. For research activities, the simplest form of the stage-gate is usually used, a start gate and a stop gate. The perceived main purpose of the gates is to facilitate communication and feed the strategy process.

Company C clearly separates between technology development and product development, like the other companies, where TRL 6 [15] is defined as the breaking point. The stage-gate model implemented is quite similar to the one used in VAC [5]. Each individual technology should pass through seven gates, one gate per TRL level. When clearing the TRL 6 gate, the technology is considered mature enough to enter into product development. Usually a project includes several different technologies that, combined, will give a new solution. A project may also contain different technologies that compete and address the same need in different ways. The project will have to pass through a series of Business Gates and Technical Gates. At these instances, the different sub-technologies are reviewed relative to the TRL scale and may all be at different levels of maturity. However, when combining different technologies to realize a solution, all included technologies should be at TRL 6 prior to proceeding to the development of the technical system, which is to be implemented in production.

Company D has implemented one Stage-Gate model that covers all development stages, from research to delivered product, and corresponds quite well to the commonly used NPD model (see, e.g., [9]). The model is based on a similar model from Ericsson called PROPS [25]. It incorporates seven stages and eight gates, where the first two stages cover technology development and end with Gate 3. Early investigations of concepts or technologies are conducted between Gates 1 and 2. At Gate 2, one or more possible concepts should be available that are further pursued until Gate 3. At Gate 3, one concept may be proposed and decided for further development. At this stage, the concept and included technologies should have reached a maturity so high that risk is considered low enough to initiate full product development. Even though this company has not implemented an adapted Stage-Gate model to technology development, they express that they are quite happy with their approach.

4.3 On the leveraging of technology through a platform strategy

"Platform strategies for a supplier in the aircraft engine industry" [6]

1. Companies A, B and C have all implemented a platform strategy. Company D wants to develop and implement a platform strategy but has not yet come that far in this process. The first three companies define their platforms quite differently.
   Company A is well-known for applying a strict modularized product platform, which they have done for many years with great success. They have one product platform that is the foundation for all product development.
   Company B implemented a process platform two years ago.
   Company C has a technology platform where five different platforms are included. The company offers tailor-made customer solutions by drawing on the capabilities in the five platforms.
2. In the study at VAC, a proposal was made for a platform approach involving a product platform and a technology platform. The role of company A as system architect and integrator controlling the component interfaces is not held by VAC. The role is more similar to that found in company C (i.e., supplying components and sub-systems to be integrated in a larger system). The proposal that VAC should adopt a technology platform is thus supported by findings from company C. Similar to the situation in company B, lead time and cost in the development projects is often driven by production aspects. Furthermore, the production has to support a range of different products in different families, a situation also similar to that found in company B. This would indicate that a process platform, as chosen by company B, may well be a viable approach for VAC. In fact, the proposal, as presented in [6], has been later revised, and a process platform has been added at the same level of concretization as the product platform. The platform is being explored in further work at VAC today. In company B, the process platform had been formulated at a high level of concretization, modularizing parts of the process with defined interfaces, and this level of concretization may be investigated at VAC as well.

"Exploring the Potential of Applying a Platform Formulation at Supplier Level - The Case of Volvo Aero Corporation" [7]

In *company A,* there is only one product platform. From this platform, different variants are generated serving different product sizes, applications, generations and customers. The platform continually evolves through small incremental steps. In *company B,* they have seen that one process platform could very well serve as a foundation for several different product families. What defines the process platform is the different process steps taken when producing the products. If the process flow is similar for different products, then a common platform could be established and used. The process platform constitutes, in its concrete form, of machines with well-defined interfaces such that one machine can be replaced by another one. The idea is that an individual machine can be taken "off-line", rebuilt to new needs, and then made "on-line" again without impacting the whole process flow. Nevertheless, the company has chosen to link the different process platforms to the product families, meaning that product family A is based on process platform A. The reason for this has more of an organizational character than a technical. The organizational complexity of coordinating the development of the process platform with different product areas, having factories all over the globe serving different markets, was simply seen as too difficult. Therefore, the boundaries for the platform have been set more narrowly. In *company C,* the whole idea is to utilize the capabilities in the five technology platforms to meet the needs of their customers. However, it is not clear from our limited interview material to what level of concretization this reuse is realized. The unit in which our interviews were conducted serves one of the five platforms to "99%". This also means that the people we talked with had very limited experience of the other platforms and their exploitation.

5 DISCUSSION

On technology and its process of development

Many of the results found at VAC and described in [1-7] have also been found in the four companies included in this study. An interesting aspect, that could potentially be worth exploring further, is the fact that so little confidence is placed in general on the forecasting capabilities of the product planning. One would be tempted to conclude that the studied companies predominantly employ technology push. However, this is not our conclusion. All the companies work with long-term planning and attempt to anticipate future market needs. However, uncertainty regarding this planning is usually high, and a combination of planning, more or less long-term, with a flexible approach of gradual market validation of explored technologies, has been found. To find a model for the dynamic balancing of forecasting capabilities and the explorative development where new knowledge is one of the major results may be an area that should be further investigated.

On normative process models and technology development

All the companies utilize some structured model for managing technology development, and the stage-gate model appears to be one of the generally chosen methods. The different model implementations differ between the companies. All appear quite satisfied with their respective implementations. This indicates that the conclusions in [4] regarding the usefulness of the model appear valid and agree with results reported in other literature [10, 11, 26]. In all the studied cases, they apply the model more loosely than what is done in later development phases. They also use the model more iteratively than what is usually acceptable in product development. There was an almost unison message from the companies that the main result from the process is one or more concepts where the risk is proven sufficiently low to select the concept for product development.

On the leveraging of technology through a platform strategy

All the companies have chosen different platform strategies. Evidence from the four companies support a modification of the approach proposed in [6]. However, several of the changes have already been implemented in the continued work on platforms at VAC, and that implementation lends extra support to the claim that these alterations are well-founded. The modifications include adding a process platform to complement the product and technology platforms. Furthermore, in the continued work at VAC, efforts are being made in particular to formulate product and process platforms at a level of concretization that makes sense to the company. Exactly what this means remains to be seen in the continued work on formulating platforms in the company, and in this type of supplier context. We have not investigated in detail the rationale in companies A, B and C for deciding on their respective platform approaches. Our impression, though, is that assessments regarding what is “core” and what is “variety” in the company offerings have been discussed and analyzed in the organizations, an approach previously discussed by Sawhney [16], for example. Sawhney argues that understanding the common strands that tie the firm’s offerings, markets and processes together for the creation of leveraged growth and variety is the simple insight that is the foundation on which platform thinking lies. The role of company A as system architect and integrator with a need to offer their customers a broad product range while still maintaining manageable costs makes the modularized product platform [17] a logical choice. The products of company B can be considered as relatively simple. However, the machines and production system of the company are highly sophisticated, with a capability to produce a broad product range. To achieve efficiency, both regarding product development and quickness in market response, choosing a process platform [18] appears to be a sound choice. Company C addresses a broad market and many different types of systems for their products. The technology platform approach [19, 20] serves as a foundation for the major generic capabilities utilized when providing the customers of the company with tailored solutions.

Reflections regarding the quality of this study

The purpose of our study has been to investigate to what extent we can claim that the results obtained at VAC apply to other environments as well. We can conclude that many of the findings from VAC also apply to the four companies included in this study. In general, although variations clearly exist, many similarities have been found.

When judging the trustworthiness of the results from the work, we return to the quality criteria adopted from Yin (2003) and described in Chapter 3. *Construct validity* of the study is strong due to the various steps taken in the study. Replication has been achieved, and some level of “statistical generalization” [22] can therefore be claimed. In addition, *external validity* can be claimed to be high. This is because findings from Volvo have been compared with results, both those reported in literature and those replicated between the four company cases . Given this, how broadly we can claim external validity can still be discussed. The chosen companies are all mature, as are their products, and most development is conducted in incremental steps. Implementing platforms appears logical in that environment, but is not equally obvious in a more dynamic environment. The size of the organization may have an impact on the usefulness, or need, of the stage-gate model. Company D, where very few people were involved in technology development, used a model that was not that developed. Yet they were satisfied with their approach. In comparison, in the other companies having more developed models, a greater number of stakeholders were normally involved in development. This resulted in a greater need for a structured approach to coordination and consensus building. Finally, *reliability* - the possibility of another researcher repeating the same study - has been considered by documenting the different steps taken during the research in accordance with the description in Paragraph 3. In general, we believe that the trustworthiness of the results can be considered high. However, expanding the number of companies included, as well as including more interviewees in all companies, clearly would have increased the quality level further.

6 CONCLUSION

Our research question in this study has been the following: "*Do obtained results from the unique context of Volvo Aero Corporation apply more broadly in industry?*"

What we can conclude is that most of the results previously obtained in VAC have also been found in the four companies included in this study. The fact that these companies represent quite different types of products lends additional strength to the external validity. Quite naturally, differences have also been found, and some of those have been discussed in this paper.

Apart from providing this answer to our research question, this article contributes empirical results from five different contextual settings concerning aspects of technology development. Finally, the results obtained have been compared with those of the different cases. In addition, reflections have been made relative to what has been reported from earlier studies at Volvo Aero Corporation and thereby indirectly to what can be found in the literature.

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