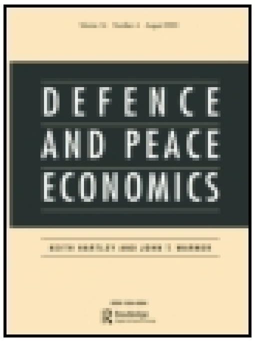

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Affordability Aspects in the Development of Defence Equipment: Case Studies of Concept Generation in the Defence Industry

Daniel Amann[a,b], Ingrid Kihlander[a] and Mats Magnusson[a]

[a]Integrated Product Development, KTH Royal Institute of Technology, Stockholm, Sweden; [b]Department of Military Studies, Swedish Defence University, Stockholm, Sweden

ABSTRACT
Cost escalation for many complex defence equipment is arguably not sustainable. Customer driven requirements have led to an exponential increase in costs by pushing frontiers of technology to support primarily incremental improvements of traditional equipment concepts. Accordingly, affordability has become a more discussed subject in defence acquisition. This paper addresses the process of generating complex defence equipment concepts. The purpose is to explore how affordability is managed in that process and to identify possible leads to how an unsustainable cost escalation for this type of equipment can be curbed. This is done by studying two cases of concept generation of future combat air equipment systems from a company process perspective. This applied micro perspective on cost escalation showed that none of the concepts generated in these two cases were assessed to curb the cost escalation. Further, the innovation model for the generated concepts, with only one notable exception, was incremental. Nevertheless, the empirical observations from these two cases offer leads on how to potentially foster a more innovative and affordability-oriented concept generation process for future defence equipment, as well as indicating avenues for future research.

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Introduction

Many types of military equipment are affected by unsustainable cost escalations. Several studies have shown how costs for each new generation of frigates, main battle tanks, fighter aircraft and other defence equipment of more complex characteristics rise well above consumer price indices on an annualised basis (e.g. Davies et al. 2011). For example, a summary of seven studies shows annual intergenerational cost increases of 6–11% for fighter aircraft and another summary of six studies shows annual intergenerational cost increases for submarines of 3–9%, all in real terms (Hove and Lillekvelland 2016). These cost increases are based on a long run increase of costs over generations for these types of equipment and are not adjusted for any possible changes in characteristics between these generations.

According to several studies (e.g. Arena et al. 2008; Kirkpatrick 1997; Pugh 2007), the major driver for this cost escalation for complex defence equipment is an arms race between nations which implies that the cost escalation is customer driven (Arena et al. 2008). The logic is that in combat only winning counts, and the performance of the equipment is important for getting an edge over an opponent (Pugh 2007).

CONTACT Daniel Amann daniel.amann@fhs.se Department of Military Studies, Swedish Defence University, Stockholm, Sweden

Even though this bothersome development was recognised decades ago (e.g. Augustine 2015), it has continued ever since and has thereby posed significant reductions in the buying power of the armed forces. As a consequence, the forces' quantities of complex defence equipment have over time been reduced since old systems have generally not been replaced one to one, and moreover, the time spans between such replacements have increased (e.g. Kirkpatrick 1995). This has led to questioning whether future generations of military equipment can be afforded, for example, fighter aircraft (Pugh 2007). That would be particularly problematic for small nations already having low numbers of equipment for defending large areas, and it could in the end lead to military capability gaps. To avoid such a development it has been suggested that the actors in the defence sector have to consider more radical changes (Hartley 2011; Pugh 2007).

Unarguably, there is a need to change path in order to enable development of affordable equipment in the future. However, this is not only a simple matter of cost, which is clarified in the concept of affordability. Affordability is defined by the system engineering community as, ' … the balance of systems performance, cost and schedule constraints over the system life while satisfying mission needs in concert with strategic investment and organizational needs' (Walden et al. 2015, 211). In a defence setting, a suitable view of affordability is that all parts contributing to a desired capability, e.g. equipment, personnel, infrastructure and doctrine (e.g. Yue and Henshaw 2009) cannot only be balanced, they must also be contained within an allocated budget. This reasoning is in line with a very straightforward definition by the US Under Secretary of Defense for Acquisition in 2010, Ashton Carter (2010), saying that affordability is about conducting a programme at a cost constrained by the maximum resources the department can allocate for that capability. This implies, that for a specific part contributing to a capability, its contribution to the total cost must be reasonable, and thereby enable meeting the allocated budget for the entire capability. This leads us to define affordability as follows: affordability implies that an item of equipment is affordable if its contribution to a total desired capability is in a reasonable relation to its costs over its lifetime and thereby contributes to meeting the desired capability at an allocated budget. Thus, affordability is by our definition in relation to both performance and an allocated budget. By trading and balancing the parts constituting the total capability, a desired capability should in the end be met at an allocated budget. What is affordable is therefore different for different actors, depending on the size of budgets and the implications of the capabilities desired. Should an equipment concept be unaffordable it signals that the concept should be reconsidered in order to meet cost constraints and the requested requirements. Accordingly, affordability does not imply that a desired defence capability cannot be met, it is rather the other way around. When acknowledged that an equipment concept no longer, at an affordable cost, contributes as needed to a defence capability, then it is time to rethink that equipment concept. For achieving a necessary path change towards affordability in this meaning, it can be assumed that future concepts of complex defence equipment need to be radically different from the prevalent concepts of recent decades in order to be both affordable and operationally relevant. However, a path change away from unaffordable traditional equipment concepts is not necessarily anything that suppliers are striving for. There might be several reasons for preserving this status quo, but as pointed out by Hartley (2011) the major reason does not appear to be unreasonably high profit margins in non-competitive contracts. Examples of other potential reasons might instead be core rigidities (Leonard-Barton 1992) and a preference for improvements along mainstream performance attributes (Bower and Christensen 1995).

Despite a seemingly increased focus on affordability in today's defence acquisition (e.g. Carter 2010), there has nevertheless been limited attention paid to how affordability is taken into account by the defence industry in the earliest phases of their development of new defence equipment, phases often preceding formal acquisition processes. For product development in general, it has been suggested that it is by performing better in these early phases that the most significant benefits in the development of competitive products can be achieved (e.g. Khurana and Rosenthal 1998) and costs can be reduced (Cooper and Slagmulder 1999). Accordingly, affordability should be addressed already in the initial stages when new concepts are generated.

This paper therefore aims at addressing the issue of cost escalation for complex defence equipment from the perspective of how defence industries tackle this issue. By applying a micro perspective, studying company processes from the inside, we supplement earlier studies (e.g. Hartley 2011) that address this cost escalation more from a macro perspective.

More specifically, the objective of this study is to explore how affordability is managed in the defence industry in the generation of early preliminary concepts for complex defence equipment. This is done in order to understand the concept development process, and to identify enabling and disabling mechanisms for generating future affordable defence equipment. Further, this exploration will serve as a foundation for future research on developing affordable equipment. For these reasons, two recent cases of concept generation of future combat air systems have been studied. Data were collected by interviews and were analysed for each case individually as well as comparatively between the two cases.

Exposition of Theory

This section presents an exposition of theories relevant for managing the cost escalation of defence equipment. Specifically, theories related to concept development for affordability and what different innovation models bring about are elaborated on. These theories establish a foundation for the research questions formulated at the end of this section.

Propositions on How to Manage the Cost Escalation of Defence Equipment

Several ways to reduce costs for complex defence equipment have been proposed. These include the suggestion to focus on upgrades of existing equipment rather than buying new equipment, thereby reducing cost and risk (Arena et al. 2008). However, the downside of such a strategy is the problem of upholding the design and engineering parts of the industrial base until they are once again needed for the design of the next generation equipment (Arena et al. 2008). Nevertheless, with today's lifetimes of defence equipment, which can be many decades (Hartley 2011), it could be argued that this strategy of upgrades is already adopted to a large extent.

Another suggestion by Arena et al. (2008) is increased competition. However, they recognise many barriers achieving that, not least on a prime system level, and they therefore suggest that one solution might be increased competition at subsystem level. In general, any potential newcomer as supplier of complex defence equipment faces huge barriers (Bellais and Droff 2016; Dombrowski and Gholz 2006; Heidenkamp, Louth, and Taylor 2013) and accordingly, it appears as if established manufacturers of complex defence equipment do not need to worry much about increased competition from new actors on their established markets.

Collaboration among nations and companies is also a suggestion for cost savings by, for example, cost-shared R&D and economy of scale in production. However, collaborations are not necessarily as promising as they intuitively might appear, e.g. due to inefficiencies in bureaucracy and work sharing (Hartley 2011; Kirkpatrick 1997). Experience from the USA, of collaboration in the form of joint aircraft programmes between the US military branches, is recognised as being so negative that RAND recommends the US Department of Defense to avoid a joint acquisition approach for the next generation of fighter aircraft (Lorell et al. 2013).

There are also more radical suggestions for cost savings proposing new concepts for projecting power, for example, by replacing manned systems (Bangert, Davies, and Watson 2017; Hartley 2011).

Generating Affordable Equipment Concepts

In general, development of new products starts with planning and concept generation. The product concept is defined by an approximate description of the technology, working principles, and form of the product. Further, it constitutes a concise description of how the product will satisfy the customer needs. The concept generation process explores the space of concepts that may meet these customer needs (Ulrich and Eppinger 1995) as, for example, performance and price. Early preliminary concepts are generated in order to create a starting point for a concept selection phase in which a large set of such preliminary concepts are evaluated and narrowed down to a smaller set (Walden et al. 2015). After several iterations, a final concept is chosen (Ulrich and Eppinger 1995). Thus, by in this way feeding the concept selection phase with concepts to evaluate, these preliminary concepts play a critical role in the development of successful products (Girotra, Terwiesch, and Ulrich 2010), not least since poor concepts can rarely be manipulated in later stages to compensate for early misjudgments (Ulrich and Eppinger 1995).

Idea generation for new concepts may be the most creative of any activities in product development (Ulrich and Eppinger 1995). Unfortunately, generating good ideas has shown to be no easy task (Cooper, Edgett, and Kleinschmidt 2004). When generating ideas, one often recalls a familiar solution without considering true alternatives (Ward 1994) and thereby possibly missing opportunities to make dramatic improvements, by for example unorthodox concepts. This tendency to follow the path of least resistance is quite robust and has been shown in experiments to be abandoned for more creative processes only when the participants were highly constrained (Morreau and Dahl 2005). Another study (Scopilleti et al. 2014) showed that financial constraints led to a parsimonious mindset, but also to ideation of more creative products. Since the fulfilment of financial constraints is part of the definition of affordability (e.g. Carter 2010), it indicates that affordable products might be more creative products.

Creativity is certainly needed to explore the many possible combinations in the search for an affordable concept. The combinations of functions and equipment constituting a military capability (Yue and Henshaw 2009) are from an affordability perspective to be seen as a system of systems with primary and enabling systems at different levels (Walden et al. 2015). Since it has been argued that relationships at all levels of a system hierarchy must be open for trading (Bobinis et al. 2014) affordability implies a great many options open for trade when complex military equipment concepts are generated. This trade is likely to affect not only the life cycle costs for specific equipment but also life cycle costs for other equipment and functions needed to build and sustain the required capability like, for example, support systems, infrastructure and personnel. Therefore, to understand if an item of equipment is affordable this tradespace needs to be consistently defined (Walden et al. 2015). The cardinal rule for targeting a maximum cost in product development – never to exceed the allowable cost – is to be managed by offsetting costs elsewhere within a tradespace (Cooper and Slagmulder 1999).

This compliance of cost targets by offsetting costs, not only within the boundaries of a system but also within an entire military capability over its lifecycle certainly stands out as a delicate balancing. This act of balancing resources to achieve a desirable effect is central to the concept of affordability but can also be recognised in military doctrines, for example, the former British Air and Space Power Doctrine (MoD 2009, 18) stating that: '[m]ilitary aircraft use cutting-edge technology. Inevitably, this comes at a cost, but this must be balanced against the multiple and adaptive capabilities delivered, while history demonstrates that even slight technical shortfalls in the air environment are punished very heavily and usually with devastating consequences'.

This balancing reasonably implies that resources, like technologies and systems, in many cases need to be exploited in new ways in order to meet affordability criteria. Accordingly innovation explained by Schumpeter (2017) as employing existing resources in different ways – in new combinations, is the key to affordability.

What Different Innovation Models Bring About

In the defence sector, the tendency to follow the path of least resistance appears to be quite common. According to Bellais and Droff (2016), innovation in the defence sector is mainly based on a next generation principle where the frontier of many technologies, technologies that also characterised previous product generations, are pushed forward along an established path. They explain the reasons behind this strong technological continuity as a consequence of the desire to preserve industrial capabilities and to maintain a strategic dominance through state-of-the-art systems. Furthermore, they argue that this continuum does not mean that there are no significant improvements between two generations of platforms, but that it constitutes a truly high barrier for both technological and innovative disruptions. This model of incremental innovations, improvements of established products, is in general also recognised to be favourable for the business of incumbent companies (Dombrowski and Gholz 2009). However, according to Bellais and Droff (2016) the technologies currently dominant in defence systems have reached a point where additional improvement of performances normally comes with higher marginal costs and very limited benefits. They conclude, that since budgetary resources do not increase at the same rate as the cost of marginal improvements this next generation-focused model of defence innovation appears unsustainable.

Accordingly, this development pattern of incremental innovations for dominant military technologies can be illustrated by the more general theory of S-curves (Foster 1986) which suggests that the performance of a product moves along an S-curve until the performance improvement flattens out at the top of the curve. To move on from that point, more substantial performance improvements require more radical innovation – new, unique and discontinuous – relative to previous accepted practices (Norman and Verganti 2014). By radical innovation, a new S-curve with an acceptable potential for performance growth can be established (Garcia and Calantone 2002).

By the theory of disruptive innovation (Bower and Christensen 1995), new products with significantly lower price and cost might arise by market entrants approaching alternative customers in low-end market segments. These products typically bring about new value propositions often based on lower performance in terms of the traditionally perceived dimensions. Over time, such products might develop to also be preferred by customers in high-end market segments, leading to a disruption of the market for the products of a traditional type. However, the theory of disruptive innovation must be carefully applied to imperfect markets, such as the defence sector, where suppliers are totally dependent on, and reactive to, their few customers (Dombrowski and Gholz 2006) who typically focus on incremental improvements to their traditional platforms (Brimley, Fitzgerald, and Sayler 2013). Would the military customers make a conceptual breakthrough anyway, opening up for alternative product concepts based on new sets of preferred attributes, such change would not necessarily be embraced by the established firms (Dombrowski and Gholz 2009) and the barriers for alternative suppliers are huge (Dombrowski and Gholz 2006). Nevertheless, innovation regarding the concept of systems and their combination of capabilities is likely to be in the center of the future evolution of the defence sector (Bellais and Droff 2016).

Research Questions

In this research study our ambition is to answer the following questions:

- How is affordability managed when preliminary concepts for complex defence equipment are generated?
- How does the applied concept generation process influence the innovation model?
- What factors influencing the process of generating affordable defence equipment concepts can be identified?

Research Setting and Method

This explorative research study is based on the phenomenon of unsustainable cost escalations for complex defence equipment and therefore utilises a phenomenon-based approach as defined by von Krogh, Rossi-Lamastra, and Haeflinger (2012). Even though the cost escalation for defence equipment is an international phenomenon, this study is primarily conducted in a Swedish setting. This section describes the research setting and discusses choices of approach and method for this study, as well as its quality aspects. A short introduction to the studied cases is also given.

Research Setting

The Swedish government has stated principles for the supply of military equipment which imply that the needs and tasks of the combat units, the war-time organisation, should be governing; the operational requirements for the defence forces should be fulfilled. In order to achieve that, supply of equipment should be secured in accordance with the following order of priorities: (1) maintenance and upgrades of the equipment in service, (2) procurement of existing and field tested equipment, (3) new development when needs otherwise cannot be met. However, these priorities are not necessarily relevant for two areas identified as Swedish national essential security interests: combat aircraft capabilities and underwater capabilities (Olsson and Nordlund 2017).

Formally, in the Swedish defence acquisition process, the armed forces are responsible for developing and choosing conceptual solutions while the defence procurement agency is responsible for the procurement, including developing technical requirements and choosing the supplier. For strategic, high cost (approximately more than 20 million €) or specifically pinpointed equipment the government has, however, the final say (Olsson and Nordlund 2017).

Nevertheless, even though the armed forces are responsible for developing conceptual solutions, the industry can actively participate in government-initiated studies. Moreover, the industry, on their own initiative, also performs studies of new concepts which they in the end might propose to the armed forces and lobby for. This means that new conceptual solutions might very well have their origin in the industry, which for example the Gripen aircraft is an example of (SAAB 2007). Traditionally the bonds and connections between the Swedish Armed Forces and the Swedish defence industry are tight, and despite a strategy of buying off the shelf and participating in international collaborations, there are incentives for the armed forces to maintain the national defence industry (Olsson and Nordlund 2017).

Research Approach

The empirical base of this research study consists of two defence studies of future combat air systems. Therefore, a case study design has been used since it is beneficial when trying to understand the dynamics within a single setting (Eisenhardt 1989). Furthermore, using two empirical cases enables a wider range of observations, and allows for comparisons through a cross-case analysis. The first case is a defence study with the purpose of defining technology needs appropriate for a future generation of military air systems beyond 2025. The study is a government-initiated collaboration between several European nations – authorities and defence industries – which started in 2005 and concluded in 2019. The second case is a defence study with the purpose of ensuring options for future air combat capabilities beyond 2040. This study, initiated and led by a single company in the defence industry, was initiated in 2014 and is still ongoing with a primarily national scope. In this article, these two future-oriented defence studies will be referred to as case Alpha and case Beta.

The two cases were selected as they represent suitable examples of complex defence equipment, due to their contemporary status (even if they were initiated approximately 10 years apart which, in turn, is a consequence of the defence sector's contextual parameters of very long lead times), similarities enabling a more detailed cross-case analysis, and because of availability. Moreover, the two cases offered opportunities to explore both an international collaboration as well as the work by a single nation. The international collaboration, case Alpha, was studied through focusing on the efforts of one of the participating nations, and some of the participants in that study also participated in the national study, case Beta. Finally, the research team has been able to utilise a deep understanding of the defence sector thanks to the background of the main author as responsible for procurement planning and equipment programme management within the Swedish Air Force. This has enabled the search for, and access to, documentation, and greatly facilitated the selection of, and contact with, relevant organisations and respondents. The risk for bias has been mitigated by an awareness of this potential risk and by continuously critical discussing choices, interpretations and conclusions within the research team. We thereby consider that the benefits of the main author's background outweighed the potentially negative aspects.

Data Collection

Empirical data have mainly been collected through in-depth interviews with representatives from the industry and defence authorities. Document search in internal documentation concerning the two defence studies has been used as a complement throughout the research study.

A basic interview guide was developed in order to capture the aim of the study. The basic guide was then updated into two versions in which some details identified in case specific documents were added for each case. Semi-structured interviews were conducted, using the possibility to modify the pre-determined interview questions and add follow-up questions during the interviews if needed (Robson 2002). The interview guide included both general questions regarding the applied concept generation process and more specific questions probing the subjects of directives, priorities and innovation. Additionally, the respondents were requested to rank the importance of a number of attributes for the concepts. The set of attributes was case specific and was taken from internal documentation relevant for case Alpha and case Beta, respectively. Examples of such attributes were operational effectiveness, cost and risk.

The respondents were selected based on their roles in the cases, using purposive sampling (Bryman 2008). This selection was made in collaboration with the project manager for each of the two defence equipment studies. The two lists of respondents were judged as capturing the core of the two cases seeking out 'the person(s) who are best informed about the data being researched' (Voss, Tsikriktsis, and Frohlich 2002, 206). In order to validate who should be interviewed, each respondent was asked, during the wrap-up of each interview, to refer to other respondents they thought should be interviewed regarding the case. The respondents were contacted by email and all contacted respondents agreed to be interviewed.

Seven interviews were conducted regarding case Alpha, the European collaboration. The respondents were selected to represent one national defence procurement agency (two respondents) and one of the industrial companies (five respondents) performing the hands-on development work ordered by the different nations' defence procurement agencies. In case Beta, the industry-initiated study, seven interviews were conducted. Six of the interviews in case Beta were made with representatives from the industrial company and one interview was made with a representative from the defence procurement agency (who in this case was acting as the point of contact and not as the principal as in case Alpha). In both cases, the representatives from the industrial company covered both managerial and specialist roles. Some of the respondents were, in two separate interviews, interviewed about both case Alpha and case Beta. The interviews were performed in Swedish and conducted at the premises of the respondents, except for one interview held at the Swedish Defence University and one conducted by telephone. All interviews were performed, recorded and transcribed by the main author.

The documents analysed were internal, often confidential, reports and presentations used to provide some facts, and to explain definitions, acronyms, wordings, etc. The knowledge captured from these documents informed the interview guide and was used as a triangulation factor in the data analysis.

Data Analysis

The data analysis was performed manually in order to capture new and unforeseen relations in this emerging and under-researched topic. In the absence of an established framework and terminology a structured explorative approach, inspired by the work of Gioia, Corley, and Hamilton (2012), was chosen for navigating through the empirics.

Based on the transcribed interviews and the identified documentation, each case was first individually analysed and then a cross-case analysis was conducted. The transcribed material was complemented by revisiting the documents found in the document search when clarifications or complementary facts were needed, for example, about definitions and details in processes. Another step was to arrange the material into a matrix model displaying every respondent's answers to each question in the interview guide, including regrouping parts that could contribute to answering some of the other interview questions. The answers from the different respondents were summarised for each interview question and reduced by triangulation. The relevance of each respondent's answers was weighted during the triangulation in relation to the respondent's participation and responsibilities in the different parts of the process. The data from this first-order analysis were now, in a second-order analysis, once again in a similar way regrouped, summarised and reduced into four new groups. One group containing data generally describing the cases and their contexts, while the content in the other three groups were grouped in order to enable reliable and valid answers to the three research questions. Finally, a cross-case analysis was performed, contrasting the cases by looking for similarities and differences as a basis for overall conclusions (Eisenhardt 1989).

The analysis was made by the main author, looping each step such as interview transcriptions, case matrices and summaries within the research team in order to discuss and compare what the empirical observations revealed.

Quality Aspects of the Study

In order to present research with good validity, i.e. to 'investigate what one wished to investigate' (Kvale 1983, 191), we have carefully selected appropriate cases, respondents and methods when trying to answer the defined research questions. We are aware that interviews, e.g. personal testimonies, as the main empirical data require high quality in the interpretations done. To mitigate this challenge, we saw the use of document search as an opportunity to capture complementary information, to clarify and for triangulation.

Nevertheless, only two cases, both covering future combat air equipment concepts, and 14 respondents are of course limiting for how these findings can be generalised to complex defence equipment in general. Certainly, differences between different cases can be expected, however, we assume that the findings from these two cases are generalisable to many other similar cases of complex defence equipment development. This assumption is in line with how literature (e.g. Bellais and Droff 2017) generalises R&D mechanisms for this type of equipment and, not least, on the fact that in one of our cases several of the major defence industries in Europe were indirectly represented.

Finally, a limitation concerning both validity and reliability is that the individual capabilities of the people who generated the concepts were not surveyed. Since the difference in idea generation performance across individuals is generally large and highly significant (Girotra, Terwiesch, and Ulrich 2010), it is difficult to say whether it in the end was the process or individual capabilities that mainly affected the outcome of the concept generation process. However, since the concept generation teams in the two cases involved several people we suggest that there reasonably was a mix of individuals' idea generation performances, and accordingly a mix of the degree of novelty among the preliminary equipment concepts generated by those different individuals.

To fulfil requirements of reliability the data collection and analysis have been carried out as thoroughly as possible. Transparency has been employed within the research group, for example, by discussing different choices and interpretations made. Nevertheless, we are aware that the risk of undesired influences from biased respondents or research team members can never be fully eliminated. Finally, we have given account for the process in an as detailed manner as possible, given the paper format restrictions.

Results and Analysis

This section presents the results from each case and the individual within-case analyses, as well as a cross-case analysis. The results show that all of the generated equipment concepts in both cases were assessed to be more expensive than the company's present fighter aircraft and the innovation model was primarily incremental.

About the Cases

The two cases are future-oriented defence studies on future combat air systems, carried out within the defence sector. One of the cases is a multinational defence study while the other case is a national defence study.

Both of these defence studies, case Alpha and case Beta, applied a systems of systems approach where a future combat air system was defined as a concept consisting of one or more components. A component was typically a manned or unmanned flying vehicle including their type specific support systems, e.g. a fighter aircraft with weapons and type-specific ground support systems. The concepts and their components should also relate to enabling systems and other military systems in their surroundings, which we understand as being primarily legacy systems like, for example, air-to-air refuelling aircraft and command and control systems.

A complete concept should be able to fulfil for each case specified military missions. Therefore, identification of operational requirements preceded the generation of the first preliminary concepts. However, the preliminary concepts generated were evaluated not only relative to operational requirements but also relative to other factors like, for example, costs and risks.

Costs for each concept were estimated out of a life cycle cost (LCC) perspective. Differentiated costs for participation in operational campaigns were also estimated, including costs for support from some systems outside the concept boundaries like, for example, air-to-air refuelling. The context for possible cost trade-offs was therefore rather wide and cost trade-offs were done within the concept boundaries as well as across the boundaries.

Finally, it should be emphasised that neither of the cases aimed at defining a concept to be immediately ready for development and subsequent production, but rather to identify new technologies and options for future air combat capabilities.

Case Alpha – A Multinational Defence Study

Results

The purpose of this multinational defence study was to identify technology needs to support future combat air systems in the time frame of 2025. The nations participated with industry and government representatives. Initial values were the time perspective and that the concepts should fall within the frame of what was defined as operational combat systems. No cost constraints or any directives to curb the cost escalation for fighter aircraft were given. One respondent expressed that, 'in the authorities' discussions with the industries LCC was not in focus'.

The generation of concepts was performed by brainstorming, and initial assessments were primarily done relative to the operational requirements. The respondents reported that they had not harmonised their pictures of cost drivers before the preliminary concepts were generated, but they were of the opinion that each of them generally had a clear understanding of what is driving costs. One respondent stated that the generation of concepts was based on a 'feeling' for getting close to what was requested, and that this feeling stemmed from earlier experiences. Factors, like cost and risk, were mainly assessed later into the process.

By a brief analysis of the generated concepts that had passed the first iterations, the respondents could, at the time for the interviews, identify that operational requirements had been the primary focus. In the same way, it could be noted that all these concepts were considered to be more expensive than the company's present fighter on the market.

The respondents considered the degree of innovation to be low and the different types of components were as such not new for the company, and some components were even upgraded legacy systems. The respondents were under the impression that they at least initially had been willing to take risks: 'We never thought of staying out of doing something because the risk was too high, it was rather we who were limited in being innovative'. Among the respondents, there was different reasoning about why the degree of innovation was so limited. One opinion was that aspects of consensus in the cooperative setting can have deselected innovative components. Another thought expressed by respondents was that the company has a niche in manned fighter aircraft, based on its excellent knowledge, that they wanted to preserve. Other expressed explanations included conservatism and traditional thinking.

Analysis

The early concepts generated in this defence study were not assessed to curb the cost escalation of fighter aircraft. However, the aim was primarily to identify technology needs and it can therefore be assumed that the process and the participants considered this aspect to a higher degree than costs. An absence of constraints, in form of directives regarding maximum allowed costs and the need to curb cost escalation, was not helpful in supporting a path change (Morreau and Dahl 2005) and certainly contributed to maintaining the trend of rising costs.

This future-oriented defence study failed at taking any big leaps in the conceptual design of the components, and the innovation model can be considered to be incremental. There may be several reasons for the observed lack of innovation. In this specific case, a cooperation between different industries may imply some disadvantages. Consensus decision-making and large teams are claimed to hamper the degree of innovation (Wu, Wang, and Evans 2019). As further barriers for innovative concepts in this cooperative setting, respondents mentioned limited openness, prestige, different agendas and different interpretations.

Case Beta – A National Defence Study

Results

This national defence study was initiated with the purpose of giving the business management of an industrial company an understanding of the market beyond 2040 and ensuring options for the future. The study manager was directed to take big steps in systems and technology. The importance of creating knowledge was commented on by one respondent, 'even if you develop a bad concept, the created knowledge, the lessons learned, can sometimes, in some meanings, be as important as developing a successful concept'.

The concept generation aimed at a solution-space including manned and unmanned air vehicles with different levels of technology. Limits were to be pushed by emphasising thinking beyond present products and beliefs in order to capture and utilise radical new technologies and system solutions. There were no other initial values explicitly given than those mentioned above, hence no cost constraints or directives to curb the cost escalation for fighter aircraft. However, some respondents mentioned the company's present fighter on the market as a benchmark for costs.

The preliminary concepts were generated by brainstorming about which operational requirements were in focus. Early assessments were based on the participants' earlier experiences with influences from thoughts of other actors, general trends and earlier studies. Factors successively brought forward, and considered most important next to operational requirements, were cost and business opportunities. The relative importance of these factors was expressed by one respondent as, 'I believe it was operational effectiveness, business and cost – in that order'. Cost was, however, more considered a constraint, a parameter in the coming evaluation, something that maybe could be tweaked or later reduced.

By looking at the concepts that survived the first evaluations, respondents could identify that operational requirements had been the dominating factor during concept generation. These concepts were also generally considered more expensive than the company's present fighter on the market. The real costs were however considered difficult to intuitively estimate since they are dependent on possible industrial cooperation, size of the customer base and how recurring costs and operational costs interact in the build-up of the LCC. The participants did not have any harmonised opinion about what drives costs. However, the respondents referred to the fact that they on an individual basis have a good understanding about cost drivers based on their previous experiences. Cost consciousness appears to be a part of the company culture and low-cost is a niche market for the company.

Concepts in form of these high-level systems of systems were new for the company and several of the components forming these concepts were categorised as new types of products to the company's activities and business. One component was even considered a radical new solution while, on the other hand, another component was just an upgraded legacy fighter. Noticeable is that the radical new component was considered among the cheapest of all of the generated components.

Creative thinking was encouraged and the respondents experienced that they had been willing to take risks even if they also generated some low-risk concepts. Nevertheless, there were thoughts expressed that the generated concepts did not really reflect the technology level of 2045, that they were just conservative extrapolations, and that it was not as creative as it could have been. Reasons for this mentioned by respondents were: there is a threshold for many to leave the traditional, it is difficult to leave the comfort zone, and it is about personal qualities. One respondent stated that top management has hampered the willingness to take risks, 'there are sometimes opinions that a solution could have very good qualities but that the customer probably does not want it'.

Since the start, the main focus of this defence study has, in dialogue with the lead customer, changed from what will replace the company's present fighter on the market to how to best support incremental upgrades of that aircraft. Consequently, the main time focus has changed from beyond 2040 to 2035 and the ambition to study new air vehicle concepts has been largely toned down. Instead, the study now focuses more on functions that could be implemented more independently of platform and an expansion of the concept boundaries is discussed.

Analysis

Even though one of the aims of this national defence study was to ensure options for future air combat capabilities, costs were not in focus and none of the generated concepts were assessed to curb the cost escalation.

Anyhow, the respondents assessed the degree of innovation to be rather high, including a radical new component. Management directives to look beyond present products and beliefs may have pushed this innovation. However, compared to what is written in specialist press and reports about, for example, drones and swarms (e.g. Stillon 2015), the different concepts do not appear quite as unique as argued, at least not as ideas.

A low-cost niche, implying cost constraints, might have been positive for evoking creativity (Scopelitti et al. 2014). An expansion of the concept boundaries logically opened up for exploiting more possible solutions. Later directives to focus closer in time may, on the other hand, have been negative for the possibility to take big innovative leaps. As reference, the R&D process for the Eurofighter involved as much as 18 years from start to first service delivery (Hartley 2011), even though it has the same basic concept as its predecessor. Thereafter, another couple of years were required until the first fighter squadron reached full operational capability.

Cross-Case Analysis

The two studies are in many aspects similar. The method used for generating concepts in case Beta was to some extent based on the method used in case Alpha and they were in general terms both in line with established methods (e.g. Ulrich and Eppinger 1995; Walden et al. 2015).

In both cases, concept generation was driven by operational requirements and in neither of the cases were financial constraints explicitly expressed nor were there any explicit directives to the curb cost escalation. Even though the tradespace was relatively big in both cases, including systems outside the concept boundaries, we find that some concepts could have benefitted from an even wider tradespace to further enable reductions of indirect costs like, for example, costs for airbases and basic flying training. A bigger tradespace logically allows more options for offsetting costs in order not to exceed an allowable total cost, the cardinal rule for cost targeting (Cooper and Slagmulder 1999). Moreover, cost offsetting was likely further hampered by no explicit common understanding of the cost drivers within the tradespace. This lack of awareness of target costs and cost drivers may be leads to why the cost escalation was not curbed.

Case Beta appears to be more successful in terms of innovative thinking than case Alpha. One reason for this may be a longer time to market, approximately 26 years as compared to 20 years in case Alpha. Longer time spans logically increase the opportunities for new technical solutions and not being locked in by the legacy. Another reason may be the case Beta company's low-cost niche, implying constraints, that may push innovation necessary to meet operational requirements at a lower cost (Scopelitti et al. 2014; Morreau and Dahl 2005). Other leads may be management directives to think out of the box, and not having the disadvantages of limited openness and need for consensus within a cooperation of competing industries.

Discussion

In this section, the results from the case studies are discussed relative to the extant theories in order to show the reasoning leading to the answers to the research questions. These discussions are divided into three separate subsections, one subsection for each research question. The summarised outcome is a number of leads which we suggest might fruitfully support the generation of affordable defence equipment concepts.

Affordability is Poorly Managed

Cost escalations for complex defence equipment have been considered a problem for many decades (e.g. Augustine 2015). Nevertheless, this study has not identified any indications of changes towards more affordable concepts of such equipment. None of the preliminary concepts of future combat air systems in our two cases were assessed to be less expensive than their predecessors. This is not surprising, given that the teams that generated these preliminary concepts did not get any explicit directives considering cost escalation and target costs. However, even though affordability was not managed explicitly, there were some ingredients of affordability aspects. For example, costs were considered (when considered) in a life cycle perspective and were also partly traded outside the system boundaries. Nevertheless, this was not enough for curbing the cost escalation and it is obvious that the concept generation processes in the two cases did not manage to override the barriers for developing equipment concepts meeting affordability criteria.

The Established Product Development Process Favours Incremental Innovation

Continuing as today, mainly along a path of incremental improvements of traditional equipment concepts, does not appear to be the right way to go for curbing the cost escalation. Accordingly, we suspect, in line with Kirkpatrick (1995), that suggestions for reducing costs by, e.g. collaboration or increased efficiency in development and manufacturing will not suffice.

Even in the studied cases, the applied processes for concept generation have not fostered necessary innovation to curb the cost escalation. Altogether, only one component, in one of all the concepts, could be considered as radically new. This component, by being assessed to be relatively less expensive, supports our suggestion that more radical new equipment concepts might be more affordable. However, the overwhelming part of generated concepts was considered to be incremental improvements. This finding, the dominance of incremental innovations, is similar to conclusions in other studies, for example Bellais and Droff (2016), and accordingly, there appear to be some fundamental mechanisms preserving that innovation model.

One contributing reason could be a need for the military operators to make sure that the original equipment manufacturer has sustained engineering knowledge. For example, in the air domain, represented by our cases, such engineering knowledge is necessary for maintaining the airworthiness of the military operators' legacy aircraft in service today, i.e. competence to handle air safety issues, design deficiencies, obsolescence, etc. By ordering upgrades of legacy systems, such necessary competencies can be preserved until the next equipment generation is ordered. In the same way, the industrial innovative capability can be sustained, which according to Sempere (2017) otherwise would have been expensive to preserve anyhow. In the light of this, a strategy of continuous incremental improvements appears rational and the change in case Beta towards a focus closer in time on upgrades of a legacy platform might be justified. However, this need to retain old competence also drives cost (Hedvall 2004), and it certainly contributes to preserving the technological continuum described by Bellais and Droff (2016). Moreover, this continuum might be further strengthen by an unwillingness of the leading incumbent companies to change innovation models. They have few incentives for such a change as long as their most profitable customers are willing to spend large amounts of money on incremental improvements (Bower and Christensen 1995).

Considering the underlying mechanisms, it certainly appears that a 'push' to stimulate the search for more radical new solutions is needed in order to assure future affordable defence equipment. When lifecycles of complex defence equipment very well might be longer than the time span of 66 years between the Wright brothers' first flight and the first man on the moon, the rate of radical innovations in today's defence equipment concepts, in a relative sense, appears to be low. Accordingly, in the two studied cases, it was difficult to identify any strong influencers that might induce a change in innovation model. What maybe could support such change, identified in case Beta, is a low cost niche and management directives about taking big innovative steps. Altogether, we conclude that the processes, as applied in these two cases, simply do not promote the innovation required for leaving an established path of incremental improvements of traditional equipment concepts.

Directives, Cost Constraints and Better Cost Trading are Helpful

Generation of new concepts starts with an idea generation of preliminary concepts. In that process, it appears unwise, as in our two cases, not to address this unsustainable cost escalation. In the process start-up, from the very beginning, explicitly expressed and 'tough to achieve' cost constraints would likely been beneficial, not only to 'guarantee' acceptable costs but also to stimulate creativity (Scopelitti et al. 2014). Constraints can be the enablers needed to give concept generation teams a push to leave a path of least resistance (Morreau and Dahl 2005) in the search for more untraditional and affordable concepts.

An example of how beneficial directives about tough goals can be in this context of complex defence equipment is SAAB's decision in the late 1970 s to develop a multirole fighter aircraft, the Gripen, within the budget for a much less advance light ground attack/trainer aircraft (SAAB 2007). This ambition was later followed up by political statements that clearly emphasised that the trend towards bigger and more expensive fighter aircraft should be broken (Antvik 2009). Even if the Gripen aircraft did not fully curb the cost escalation, at least not considering acquisition costs, the rate of escalating acquisition costs compared to its predecessor was dramatically reduced (Nordlund 2016). Accordingly, we suggest that, for curbing cost escalation it is beneficial to give concept generation teams explicit directives to do so, as well as explicitly expressed cost constraints.

In the two investigated cases the managed context was actually bigger than we had expected, and cost trading crossed the borders of the system in focus. A big tradespace logically enables more chances for offsetting costs in order to meet a target cost (Cooper and Slagmulder 1999), but also to identify alternative and "cost-effective capabilities"– the key in the analysis of the affordability tradespace (Walden et al. 2015). We suggest that by embracing an even wider context the possibility to mitigate cost drivers, and to realise a capability in other ways than just replacing an old equipment concept with a new one of similar type, is likely to increase, and thereby also the chances of meeting the affordability criteria.

However, a big tradespace alone is probably not enough, there must also be an understanding of what the cost drivers in that context are. In both of the cases, the participants only had individual and subjective opinions of the cost drivers within the context. These costs, particular in a LCC perspective, are not obviously intuitive. LCC for a combat aircraft is, for example, approximately 4.5 times the acquisition cost (Hartley 2011). Besides that, there are costs for basic flying training, weapon training, running airbases, command and control, etc. Based on figures from the Swedish Armed Forces, the authors have estimated[1] that costs for three major parts of a traditional air combat concept – fighter aircraft acquisition, fighter pilot training, and airbases – are all of the same magnitude. A combat air system concept independent of pilots and airbases could thus, potentially and roughly, afford three times as expensive weapon platform compared to a traditional concept. For enabling an effective cost trading it is therefore not enough to have a big context to trade within, it is of course also important to understand the different costs constituting that tradespace, and not least, the life cycle costs. This suggests that an improved knowledge of potentially tradeable costs among the teams generating defence equipment concepts might open up for untraditional and affordable solutions. Accordingly, Yue and Henshaw (2009) argue that affordability requires a sharing of information between customers and suppliers about costs, assumptions, objectives and strategy in a way that completely changes the prerequisites on the defence market. However, they also suggest that it might be a great challenge to establish such a relationship.

In summary, in order to curb this cost escalation, it appears as though the process of generating preliminary equipment concepts must have a clearer focus on affordability from the very beginning, with more normative approaches when it comes to costs, for example, explicitly stated cost limits. To further support the pursuit for affordable equipment concepts, we suggest it is important, when concepts are generated, to be able to trade among the different technical systems and functions building up a desired military capability. A systematic approach for defining the tradespace and for informing the participants of the concept generation team about the cost drivers in the tradespace is suggested to be beneficial for identifying solutions to cost-effective capabilities, and thereby also avoiding sub-optimisations. Further, we suggest more innovative thinking is required since we suspect that radical new equipment concepts are needed for meeting simultaneous requirements of both costs and operational effectiveness. Some identified measures potentially beneficial for furthering more innovative thinking are management directives about the degree of innovation requested, long lead time to market entry and challenging financial constraints.

Conclusions

We have explored two cases of industry executed future-oriented studies by focusing on how they managed affordability in the earliest phases of concept generation of complex defence equipment. It can be concluded that affordability was not explicitly managed, and in accordance with that none of the concepts generated were assessed to curb the cost escalation. Further, it was recognised that the process in both cases apparently favoured incremental innovation. Finally, some process enablers were identified which we recommend to be implemented in concept generation processes, and to be considered in acquisition processes as well as in preceding future-oriented studies. We suggest that these findings provide leads to how the problem of cost escalation can be fruitfully addressed.

Moreover, the study with respect to the previously mentioned limitations can potentially contribute to the theory of defence economy by explicating the dynamics between affordability and concept generation within the defence sector. Findings could also be interesting for other sectors that are characterised by complex products, public financing, public-private collaboration, oligopolies, large integrated networks of actors and long lead time.

However, generalising findings from case studies often provides challenges due to the possible singularities of the contexts. Therefore, we are cautious to generalise any findings to other contexts outside the area of complex defence equipment since the defence sector has its distinct characteristics. We understand that even this limited generalisation might be argued to be too wide since combat air systems, in focus in the cases in this study, could be considered rather extreme examples of complex defence equipment. Nevertheless, se the phenomenon of cost escalation is a general problem for complex defence equipment and due to the fact, that the companies represented by this study all have portfolios of different types of complex defence equipment, make us suggest that such a generalisation is reasonable.

Further, we suggest that more studies, with a micro level perspective, of the stakeholders' processes might bring valuable insights about why concept generation of defence equipment does not provide equipment concepts that curb the prevailing cost escalation. Important practical implications for management of affordability might be given by studying how different designed inputs to the process of concept generation, in form of directives, constraints and information, influence its outcome.

Note

1. The costs for the fighter aircraft only comprised acquisition costs whereas costs for fighter pilot training included personnel, and training equipment over a period of 30 years. For airbases, costs for personnel, equipment and maintenance of infrastructure over the same period were included.

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ORCID

Mats Magnusson http://orcid.org/0000-0002-6024-7908

References

Antvik, S. 2009. *Styrning av stora projekt: statsmakternas krav på beställarens styrning av JAS-projektet* [Control of Big Projects: The Government's Demands on the Customer's Control of the Gripen Project]. Stockholm: Management and Aviation.

Arena, M., O. Younossi, K. Brancato, I. Blickstein, and C. Grammich. 2008. *Why Has the Cost of Fixed-Wing Aircraft Risen? A Macroscopic Examination of the Trends in the U.S. Military Aircraft Costs over the past Several Decades*. Santa Monica, CA: RAND.

Augustine, N. 2015. "Augustine's Laws and Major System Development Programs." *Defense Acquisition Research Journal* 22 (1): 2–62. https://www.dau.edu/library/arj/_layouts/15/WopiFrame.aspx?sourcedoc=/library/arj/ARJ/ARJ72/ARJ-72_Augustine.pdf&action=default.

Bangert, D., N. Davies, and R. Watson. 2017. "Managing Defence Acquisition Cost Growth." *The RUSI Journal* 162 (1): 60–67. doi:10.1080/03071847.2017.1301638.

Bellais, R., and J. Droff. 2016. “Innovation, Technology, and Defence Procurement: Reform or Paradigmatic Shift?” In *Emerging Strategies in Defense Acquisitions and Military Procurement*, edited by K. Burgess and P. Antill, 205–221. Hershey, PA: IGI Global.

Bobinis, J., C. Garrison, J. Haimowitz, J. Klingberg, T. Mitchell, and P. Tuttle. 2014. “Affordability Considerations: Cost Effective Capability.” *INCOSE International Symposium* 23 (1): 287–303. doi:10.1002/j.2334-5837.2013.tb03019.x.

Bower, J., and C. Christensen. 1995. “Disruptive Technologies: Catching the Wave.” *Harvard Business Review* 73 (1): 45–53.

Brimley, S., B. Fitzgerald, and K. Sayler. 2013. *Game Changers: Disruptive Technology and U.S Defense Strategy*. Washington: Center for a New American Security.

Bryman, A. 2008. *Social Research Methods*. 3rd ed. Oxford: Oxford University Press.

Carter, A. 2010. *Memorandum for Acquisition Professionals*. Washington: Office of the Under Secretary of Defense.

Cooper, R., and R. Slagmulder. 1999. “Develop Profitable New Products with Target Costing.” *MIT Sloan Management Review* 40 (4): 23–34. http://sloanreview.mit.edu/article/develop-profitable-new-products-with-target-costing/.

Cooper, R., S. Edgett, and E. Kleinschmidt. 2004. “Benchmarking Best NPD Practises-III.” *Research-Technology Management* 47 (6): 43–55. doi:10.1080/08956308.2004.11671662.

Davies, N., A. Eager, M. Maier, and L. Penfold. 2011. “Intergenerational Equipment Cost Escalation.” DASA-DESA Economic Working Paper Series No. 1. London: Ministry of Defence.

Dombrowski, P., and E. Gholz. 2006. *Buying Military Transformation: Technological Innovation and the Defense Industry*. New York: Columbia University Press.

Dombrowski, P., and E. Gholz. 2009. “Identifying Disruptive Innovation: Innovation Theory and the Defense Industry.” *Innovations: Technology, Governance, Globalization* 4 (2): 101–117. doi:10.1162/itgg.2009.4.2.101.

Eisenhardt, K. 1989. “Building Theories from Case Study Research.” *The Academy of Management Review* 14 (4): 532–550. doi:10.2307/258557.

Foster, R. 1986. *Innovation*. New York: Summit Books.

Garcia, R., and R. Calantone. 2002. “A Critical Look at Technological Innovation Typology and Innovativeness Terminology: A Literature Review.” *Journal of Product Innovation Management* 19 (2): 110–132. doi:10.1016/S0737-6782(01)00132-1.

Gioia, D., K. Corley, and A. Hamilton. 2012. “Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology.” *Organizational Research Methods* 16 (1): 15–31. doi:10.1177/1094428112452151.

Girotra, K., C. Terwiesch, and K. Ulrich. 2010. “Idea Generation and the Quality of the Best Idea.” *Management Science* 56 (4): 591–605. doi:10.1287/mnsc.1090.1144.

Hartley, K. 2011. *The Economics of Defence Policy: A New Perspective*. London: Routledge.

Hedvall, M. 2004. “Change as a Cost Driver in Defence Procurement.” *Defence and Peace Economics* 15 (1): 101–108. doi:10.1080/1024269042000164522.

Heidenkamp, H., J. Louth, and T. Taylor. 2013. *The Defence Industrial Triptych: Government as Customer, Sponsor and Regulator*. Abingdon: Routledge Journals.

Hove, K., and T. Lillekvelland. 2016. “Investment Cost Escalation: An Overview of the Literature and Revised Estimates.” *Defence and Peace Economics* 27 (2): 208–230. doi:10.1080/10242694.2015.1093754.

Khurana, A., and S. Rosenthal. 1998. “Towards Holistic Front Ends in New Product Development.” *Journal of Product Innovation Management* 15 (1): 57–74. doi:10.1016/S0737-6782(97)00066-0.

Kirkpatrick, D. 1995. “The Rising Unit Costs of Defence Equipment: The Reasons and the Results.” *Defence and Peace Economics* 6 (4): 263–288. doi:10.1080/10430719508404831.

Kirkpatrick, D. 1997. “The Affordability of Defence Equipment.” *The RUSI Journal* 142 (3): 58–80. doi:10.1080/03071849708446151.

Kvale, S. 1983. “The Qualitative Research Interview: A Phenomenological and A Hermeneutical Mode of Understanding.” *Journal of Phenomenological Psychology* 14 (2): 171–196. doi:10.1163/156916283X00090.

Leonard-Barton, D. 1992. “Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development.” *Strategic Management Journal* 13 (S1): 111–125. doi:10.1002/smj.4250131009.

Lorell, M., M. Kennedy, R. Leonard, K. Munson, S. Abramzon, D. An, and R. Guffey. 2013. *Do Joint Fighter Programs Save Money?* Santa Monica, CA: RAND.

MoD. 2009. *British Air and Space Power Doctrine AP3000*. 4th ed. London: Ministry of Defence.

Morreau, P., and D. Dahl. 2005. “Designing the Solution: The Impact of Constraints on Consumers' Creativity.” *Journal of Consumer Research* 32 (1): 13–22. doi:10.1086/429597.

Nordlund, P. 2016. “Defence-specific Inflation – The Swedish Perspective.” *Defence and Peace Economics* 27 (2): 258–279. doi:10.1080/10242694.2015.1096571.

Norman, D., and R. Verganti. 2014. “Incremental and Radical Innovation: Design Research Vs. Technology and Meaning Change.” *Design Issues* 30 (1): 78–96. doi:10.1162/DESI_a_00250.

Olsson, P., and P. Nordlund. 2017. *Effektiv materielförsörjning: Nordiska länders strategi, organisation och försvarsindustri* [Efficient Acquisition - Strategies, Organisations and Defence Industries among Nordic Countries]. Stockholm: FOI.

Pugh, P. 2007. “Retrospect and Prospect: Trends in Cost and Their Implications for UK Aerospace.” *Defence and Peace Economics* 18 (1): 25–37. doi:10.1080/10242690600900505.

Robson, C. 2002. *Real World Research – A Resource for Social Scientists and Practitioner-Researchers*. Oxford: Blackwell Publishing.

SAAB. 2007. *Gripenkrönikan* [The Gripen Chronicle]. Stockholm: SAAB.

Schumpeter, J. 2017. *The Theory of Economic Development*. London: Routledge.

Scopelitti, I., P. Cillo, B. Busacca, and D. Mazzursky. 2014. "How Do Financial Constraints Affect Creativity?" Journal of Product Innovation Management 35 (5): 880–893. doi: 10.1111/jpim.12129.

Sempere, C. 2017. "A Survey of Performance Issues in Defence Innovation." *Defence and Peace Economics* 28 (3): 319–343. doi:10.1080/10242694.2015.1072377.

Stillon, J. 2015. *Trends in Air-to-Air Combat, Implications for Future Air Superiority*. Washington: Center for Strategic and Budgetary Assessments.

Ulrich, K., and S. Eppinger. 1995. *Product Design and Development*. New York: McGraw-Hill Inc.

von Krogh, G., C. Rossi-Lamastra, and S. Haeflinger. 2012. "Phenomenon-Based Research in Management and Organisation Science: When Is It Rigorous and Does It Matter?" *Long Range Planning* 45 (4): 277–298. doi:10.1016/j.lrp.2012.05.001.

Voss, C., N. Tsikriktsis, and M. Frohlich. 2002. "Case Research in Operations Management." *International Journal of Operations & Production Management* 22 (2): 195–219. doi:10.1108/01443570210414329.

Walden, D., G. Roedler, K. Forsberg, and D. Hamelin, eds. 2015. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*. Hoboken: Wiley.

Ward, T. 1994. "Structured Imagination: The Role of Category Structure in Exemplar Generation." *Cognitive Psychology* 27 (1): 1–40. doi:10.1006/cogp.1994.1010.

Wu, L., D. Wang, and J. Evans. 2019. "Large Teams Develop and Small Teams Disrupt Science and Technology." *Nature* 566 (7774): 378–382. doi:10.1038/s41586-019-0941-9.

Yue, Y., and M. Henshaw. 2009. "An Holistic View of UK Military Capability Development." *Defense & Security Analysis* 25 (1): 53–67. doi:10.1080/14751790902749900.