Deciphering Patent Value for Benchmarking Purposes

Insights from a Case Study on the Development of Additive Manufacturing in the Aerospace Industry

Master's thesis in Management and Economics of Innovation

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SUMMARY

Patent benchmarking is a valuable practice as companies can thereby gain understanding about their relative positioning within their industry. With the emergence of software for calculating patent scores, companies can now perform this benchmarking against competitors more easily. A lack of transparency in these scoring models however poses the question of what kind of patent value the models actually reflect and how the scoring ties to the overall patenting strategy. Furthermore, there is no one standard method for patent valuation, which further decreases the understanding for patent valuation as a practice. Understanding how to interpret potential value drivers for benchmarking is therefore crucial, yet it has been devoted little focus in the literature on patent valuation for benchmarking purposes.

This thesis proposes a transparent framework for patent valuation for benchmarking purposes. The framework aligns the overarching goals of the patenting strategy with the benchmarking process, capturing the value drivers relevant to the specific context from a firm, technology and industry perspective. The methods leading up to the framework are a literature review of the empirical and theoretical arguments for different valuation metrics, a case study to understand the specific valuation context and a patent search for gathering the necessary patent data.

The study concludes that patent valuation for strategic purposes is highly contextual. Finding a balance between comprehensive and manageable valuation processes is essential. Although the contextualization can be time-consuming, it enhances transparency and fosters important discussions about what constitutes the value of patenting.

Keywords: Patent valuation, Patent benchmarking, Patent portfolio benchmarking, Patent portfolio management

Contents

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Diogo Carvalhal Vala & Nicklas Wasenius
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1. Introduction

This section will provide a background to why further research on patent benchmarking is needed, and what contribution to the existing field of research this thesis aims to provide.

1.1. Background

As the economy is becoming all the more driven by knowledge and intangible assets (Girgin Kalıp, et al., 2022), companies want to protect those assets as effectively as possible. This has been demonstrated by the surge in patenting activity, which has been a persistent trend year after year, reaching an all-time high of 3.46 million patent applications in 2022 (WIPO, 2022). Patents are considered the most effective and updated source of technological progress (Demirden et al., 2023; Zhang et. al, 2017). Consequently, they can provide crucial insights into technological landscapes and industry dynamics.

Patent benchmarking is a prevalent practice, where a survey found that 98 % of patent owners rely on patent benchmarking for their patenting strategy, and the vast majority conduct such benchmarking at least once a year (Swycher & McMahon, 2021). Similar to other forms of benchmarking, patent benchmarking can be used to better understand the competitive landscape (Grimaldi et. al, 2015). It may help in understanding technological progress, the role of patents in protecting different characteristics as well as actors' positioning within a technological field (Breitzman & Mogee, 2002). Since patenting is expensive (Peters et. al, 2013), benchmarking may be an especially important tool in prioritizing which areas to patent within.

Understanding the strength and value of a patent is one of the aims of patent benchmarking, but for that purpose, there is no standard practice. Only looking at the portfolio size would be convenient but is not sufficient for understanding a company's positioning within a technological field. The value of the patents within a company's patent portfolio has instead been found to be largely skewed, where only a few of them constitute the major part of value, while the vast majority of patents, only have marginal importance (Breitzman & Mogee, 2002). Therefore, companies may want to capture more elements of the patents to understand their holistic value relative to the patent landscape. While several papers have proposed indexes comprising several different metrics signaling also the strength of the patent (Ernst & Omland, 2011; Lanjouw & Schankerman, 2004; Grimaldi et. al, 2018; Cricelli et. al, 2021), there is no consensus on which metrics signal the patent value most appropriately.

With the emergence of software for patent benchmarking, patent valuation scores are conveniently offered to companies to indicate the value of patents. Yet, with the lack of standard patent valuation metrics, the case company of this study finds the software valuation hard to interpret and make use of practically.

This thus emphasizes the complexity of patent valuation. Establishing how the valuation can be implemented transparently and practically is thus useful for understanding how companies can make use of the insights gained from the valuation.

This thesis practically outlines and implements a valuation framework for benchmarking on the developments of an emerging technology, additive manufacturing (AM), in the aerospace industry. The relative positioning of actors in the development of additive manufacturing in the aerospace industry is especially interesting for several reasons. Firstly, the technology could have an impact on the aerospace industry structure through a reduction of the value chain according to Singamneni et. al (2019). Furthermore, AM is a process technology, but constructs products that may have an altered composition compared to when the same product is manufactured with a traditional manufacturing technique. To what degree patents are used and their relative strength in the protection of the technology could thus constitute valuable information for decision-makers and their patenting strategy. Furthermore, the patenting activity in the aerospace industry is low, where other means of protection are used to a larger degree (Elkington, 2012). Additive manufacturing is however developed across multiple industries (Gao et. al, 2016) which may challenge the patenting practices also in the aerospace industry. The thesis thus aims to contribute to how patent benchmarking can be used as a tool for understanding the relative positioning and strategic value of patenting when new technology emerges as well as the general discussion around patenting product or process innovation.

Identifying the relative positioning within AM is also especially interesting due to the potential it has for improving the future competitive advantage of the actors in the forefront. AM produces components layer by layer, unlike traditional manufacturing techniques which are subtractive (Pose-Rodriguez et al., 2020). This in turn enables cost reductions, increased sustainability through lightweight components, and greater design flexibility (Singamneni et al., 2019). Staying at the forefront of developments could thus be important for the competitive advantage within the industry, where patent benchmarking can aid the actors in identifying their relative positioning.

1.2 Purpose

The purpose of this study is to understand how patent valuation as a benchmarking tool can be reconciled with the patenting strategy and strategic positioning in an industry.

1.3. Problem formulation and research questions

As discussed in the introduction, there is no consensus on how patent valuation should be done, as there exists a large array of valuation approaches comprising several different metrics (Lanjouw & Schankerman, 2004; Ernst & Omland, 2011; Cricelli et. al, 2021). Furthermore, it has been noted that different metrics and uses of patents may have different explanatory power as value drivers in different contexts (Girgin Kalıp et al., 2022; Harhoff et. al, 2003; Cricelli et. al, 2021; Holgersson & Wallin, 2017).

Some authors have furthermore, emphasized how industry factors can impact the value of patents (Teece, 1986; Holgersson & Wallin, 2017). In the aerospace industry established strategic partnerships, high capital requirements and safety requirements all constitute important entry barriers (Elkington, 2012), these market factors in turn affect the aims and needs of patenting within an industry (Holgersson & Wallin, 2017). Additionally, some companies may have different goals with the patenting activity depending on their strategy, such as freedom to operate, being able to block competitors, attracting financing and licensing, or engaging in collaborations (Holgersson & Wallin, 2017).

This lack of understanding on how patent valuation indexes tie to the overall patenting strategy is emphasized also in the literature as a gap, where Grimaldi et. al (2018) especially underlined the importance of readapting the valuation index to the technology, and the corresponding strategic goals of patenting. Pargaonkar (2016) furthermore also emphasized contextualizing the patent benchmarking process by taking internal strategic considerations into account in the valuation of the patent landscape. Despite this emphasis on transparent approaches to patent valuation that align the activity with the overall patenting strategy, there is a lack of frameworks outlining such processes in prior research.

This study therefore aims to contextualize the metrics presented in the literature and develop a valuation index aligned with the overall patenting strategy, through a case study on how such an index can be outlined for the case company in their development of additive manufacturing in the aerospace industry. The following main research question will in turn guide achieving this purpose:

MRQ1: How can patent valuation metrics be contextualized and aligned with a company’s overall strategic goals to improve benchmarking processes?

The main research question is in turn guided by the following sub-research questions:

RQ1: Which key metrics are appropriate to use for patent valuation benchmarking purposes?

RQ2: How can these metrics be contextualized to reflect the strategic goals of a company's patenting activity?

1.4. Scope and limitations

According to the time constraints and aligned with the considerations of the case company, the scope of the thesis was set to ensure a relevant, yet manageable patent portfolio benchmarking. First, the valuation framework is only validated on one technology, additive manufacturing, despite it being outlined with the intent of being used for guiding the patenting decision relative to the entire portfolio of technologies.

Furthermore, the valuation framework is developed through the insights from the case study on the development of additive manufacturing within the aerospace industry. To validate its generalizability, it should ideally be applied in more settings.

Moreover, patent valuation can be made for a vast number of different purposes (Girgin Kalıp et al., 2022). In this context, the term valuation is not used in the sense of financial valuation, but rather for a strategic valuation. This does however not mean that the presented framework is not valuable also in financial valuation contexts. The practical application and analysis of the framework will furthermore only be done on a patent portfolio level, but the concluded patent valuation framework enables analysis also on an individual patent level.

In addition, the geographical scope for the benchmarking is worldwide, aligned with the aerospace industry market structure and the temporal scope for patents is not restricted to ensure full coverage of the AM industry evolution. The benchmarking is also only performed on granted patents, not including published patents. This was done to ensure that the selected metrics could be applied to all patents.

1.5. Outline of the thesis

The thesis is organized into several key sections to provide a clear and comprehensive understanding of the study. The introduction sets the stage with background information, research objectives, and the study's significance. The theory section explores the strategic usage of patents, patents relative to other means of protection, patent valuation methods, and patent portfolio management methods, which are important to understand the contextual factors of the valuation index. The methodology details the research method, data collection and analysis methods, and case study design. Contextual factors, such as technological advancements in additive manufacturing and industry trends, are examined for their influence on the patenting activity. The results and analysis integrate these factors into the patent valuation index, provide strategic insights for the aerospace industry, identify critical success factors, evaluate benchmarking metrics for additive manufacturing patents, and analyze performance variations among aerospace companies. The discussion interprets the findings' implications for patent strategy, compares the research with existing literature, and offers practical considerations regarding the implementation of valuation indexes for benchmarking purposes. The conclusion summarizes key findings, discusses contributions to the field, and suggests limitations and future research directions.

2. Theory

This section will present theory related to patenting activity and the strategic value and usage of patents. The first chapter will focus on what information can be found in the patent document that is beneficial for benchmarking purposes. Then the strategic purposes for which patents are used will be outlined. Additionally, the relative strength of patenting compared to other intellectual property strategies will be presented. Patent valuation methods will then be presented and highlight which value drivers of patents have been taken into account in the existing field of research. Lastly, theory on patent portfolio management will be presented, which will highlight how companies take practical strategic actions based on the benchmarking insights.

2.1. The strategic usage of patents

Patenting means disclosing the underlying invention to the public in exchange for the right to exclude others from what has been patented (Holgersson & Wallin, 2017). The disclosure thus benefits the patentee but could also benefit competitors since the information becomes disclosed and publicly available. This section will describe the information conveyed through the patenting activity, and will thus give a background to how patents can be used for benchmarking purposes. It will also discuss when alternative protection strategies might be more appropriate than patenting, providing background to the limitations on the strategic uses of patents. The limitations may be important considerations since patent benchmarking only highlights the innovative efforts signaled by patents, without acknowledging that invention might have taken place without being protected by patents.

2.1.1. Patent elements commonly used for benchmarking

The general elements that need to be disclosed about the invention through a patent are largely standardized, which makes it possible to use these elements in the comparison of different patents for benchmarking purposes. Three of these elements have been used to a large degree in the valuation of patents: the number of citations, the number of claims and the classification of the patent into CPC codes (e.g. Girgin Kalıp et al., 2022; Ernst & Omland, 2011; Cricelli et. al, 2021). These are described in more detail in Table 1 below:

Patent element	Definition
Citations	The citations that the patent document makes to other documents
Claims	The claims define what the patent protects, i.e. the scope of the patent
CPC code(s)	CPC codes constitute a taxonomy for describing within which invention field(s) the patent belongs

Table 1. Patent information commonly used for benchmarking purposes.

The information about the citations that are made by the patents in turn gives statistics on two kinds of citation metrics. Firstly, the number of backward citations, which is simply the number of citations that the patent itself references. Secondly, the number of forward citations, which is the number of references that are made by other patents to this patent. The forward citations thus accumulate over time, whereas the backward citations are given and remain constant from the time of publication (Hu et al., 2011).

A distinguishing can in turn also be made regarding the claims, where they can either be dependent or independent. An independent claim functions on its own, i.e. it is only limited by its own limitations, whereas a dependent claim references another claim and thus is limited both by its limitations and the limitations of the claim that it references (Independent and Dependent Claims, n.d.).

2.1.2. The geographical scope and time constraint of patents

Another indicator of patent value that is not featured directly in the patent document, but that becomes publicly available information is the market size. Patents are national rights, meaning they have to be applied for in each country where protection is desired. In countries where they are not filed, patents can rather act as blueprints for imitation (Ernst & Omland, 2011). Therefore, it may be important to file patents in all markets where commercialization is desired for future purposes. Hence companies need to strategically choose where to file patents based on market importance, manufacturing locations, and potential competition. This often involves filing patents in major markets or countries where infringement risks are high. Filing patents in multiple jurisdictions can be expensive due to filing fees, translation costs, and ongoing maintenance fees (Peters et. al, 2013). Businesses must also balance the cost against the potential benefits of protection in each jurisdiction.

Furthermore, patents are restricted with regard to time. The exclusivity which a patent gives is typically restricted to 20 years (Granstrand & Holgersson, 2014) and in order for a patent to stay active for those 20 years, maintenance fees have to be paid at certain time periods (Maintain Your Patent, n.d.). This finite period requires strategic planning to maximize the commercial value of the patent within its lifespan. Effective IP strategy involves managing a portfolio of patents, ensuring there are always new patents being filed to replace those that are expiring, thus maintaining a pipeline of protected innovations.

In summary, geographic and time limitations of patents are important to IP strategy as they influence where and when a company should seek protection, how to manage costs, and how to plan for the lifecycle of their products and technologies. Effective IP strategy leverages these limitations to optimize the value derived from patents, ensuring sustained competitive advantage.

2.2. Patenting compared to alternative protection strategies

For an effective IP strategy, patenting should be considered relative to other means of protection. Two commonly used alternatives to patenting include publishing and trade secrets, which may be preferred to patenting in some circumstances. This chapter will present an overview of common incentives to choose patenting, trade secrecy or publishing for protecting an invention. It will also elaborate on how market structures and capabilities impact the patenting activity.

2.2.1. Considerations on the technological characteristics and the type of knowledge

A primary consideration to be done is to consider the characteristics of the underlying invention. Generally, patents are more suitable to protect product inventions than process inventions (Teece, 1986; Holgersson & Wallin, 2017). Since process inventions are not visible to the end consumer it may be easier to protect these through trade secrets (Arora, 1997). On the other hand, products that are not patented risk being reverse engineered (Holgersson & Wallin, 2017).

Furthermore, the underlying knowledge of the invention also affects the choice. If the invention is built upon tacit and complex knowledge, trade secrecy may be favorable, as that type of knowledge may be hard for external parties to make use of even if it is leaked, whereas simple and codifiable knowledge would be more suitable for patenting as a consequence of it being easy for an external party to understand and write down (Teece, 1986).

2.2.2. Achieving freedom to operate

One common objective for companies, when they formulate their IP strategy, is to achieve freedom to operate. Freedom to operate means the company has the possibility to conduct business as it wishes. Patenting thus achieves this purpose, since it means others cannot exclude you from commercializing what has been patented (Holgersson & Wallin, 2017). Publishing however also achieves that purpose since the publication contributes to what is considered prior art and can thus not be patented by someone else

(Holgersson & Wallin, 2017). Furthermore, patenting requires a higher inventive step than publishing, so if the invention does not reach the prerequisites for an inventive step for a patent, a publication may make it harder for competitors to patent a similar invention in the future and secure the freedom to operate for a longer time. Publishing also requires less time and money than patenting does (Holgersson & Wallin, 2017). Secrecy does not give any freedom to operate since the invention is not disclosed and another party could thereby patent the invention and exclude others from pursuing their operations in the patented area (Holgersson & Wallin, 2017).

Connected to the freedom to operate, Holgersson & Wallin (2017) underline two drawbacks of publishing compared to patenting. Firstly, patenting gives a more far-reaching freedom to operate than publishing does since patents can be used for licensing and thereby as bargaining power in negotiations. This is especially useful in highly complex technological fields where technological developments are cumulative, and where patents could block the commercialization of future patents. In such a case a company with a large patent portfolio could use it for cross-licensing to avoid the blocking (Holgersson & Wallin, 2017).

2.2.3. Exclusively capturing value

Another incentive for companies to protect invention is to ensure that they can exclusively capture the value from their R&D efforts. Patents achieve that purpose since it grants a temporary monopoly for what has been patented (Romer, 2002). Publishing does however not enable the company to exclusively capture value from its R&D efforts. Instead, others are given a blueprint for the invention. Revealing innovative efforts could however be strategically beneficial if the purpose is to influence actors to innovate in a similar direction and thereby increase the chances of setting common standards within an industry (Peters, 2013) but it is not beneficial for direct value capturing purposes.

Trade secrecy does on the other hand similarly to patents enable exclusively capturing value from the invention, and could do that for a longer time than patents since they are not restricted in time (Holgersson & Wallin, 2017). Even though secrecy may give the company the possibility to exclusively capture the value from its R&D investments, it does not provide the company the possibility to avoid trials, reach favorable positions in negotiations, attract financing, or block other firms' R&D and patenting efforts which may be important incentives to choose patenting (Holgersson & Wallin, 2017; Somaya, 2012). The previously mentioned factors may be considered indirect value capturing strategies (Holgersson & Wallin, 2017).

2.2.4. Facilitating collaboration

Issues with intellectual property are a major inhibitor of collaboration and knowledge-sharing, possibly hindering co-creation of value (Holgersson et. al, 2022; Azzam et. al, 2017). Intellectual property rights are thus a tool that can enable firms to share their knowledge more openly without the risk of their knowledge being appropriated by the other party (Holgersson et.al, 2022; Arrow, 1962).

Patents and publications can both facilitate knowledge-sharing and additionally, both practices may provide information regarding innovative efforts of the company (Peters, 2013). This signaling of innovative efforts and marking a strong position within a technological field may help other parties to find the company and commit to new partnerships (Orzenigo and Sterzi, 2010). Trade secrets do not however provide any signaling of a strong position within a technology, and if they are used in collaborations it is necessary to complement the protection with non-disclosure agreements (NDAs) as pointed out by e.g. Manzini and Lanzarotti (2015). NDAs may in turn be the most suitable in exploratory phases of technology development, whereas patents become more important during later stages, closer to the commercialization phase (Manzini and Lanzarotti, 2015).

2.2.5. The market structure and firm capabilities as alternatives to patenting

Throughout the literature, authors also emphasize that the means of protection may depend on the market structure (Teece, 1986; Holgersson & Wallin, 2017). If entry barriers are great that might suffice as a means of protection from imitation, and patents might instead be considered as additional costly means of protection (Holgersson & Wallin, 2017). Companies can also use informal means of appropriation in terms of time to market, high switching costs and learning (Holgersson & Wallin, 2017).

One of the most well-known theories for analyzing the market structure, and thus the components that may shield a company from competition as an alternative to patent protection is Porter's five force model (Porter, 1989). The five forces that according to Porter impact profitability are entry barriers, suppliers' bargaining power, buyers' bargaining power, the threat of substitute products or services and the intensity of competition within the industry. High entry barriers can in turn arise from high capital requirements, economies of scale, customer loyalty to incumbents and access to distribution channels or resources (Porter, 1989). Buyers' and suppliers' bargaining power in turn is largely determined by the degree to which there are alternatives on the market and the dependence on the individual buyer or supplier (Porter, 1989).

Porter's five forces highlight the dynamics across industries. However, within industries, capabilities can arguably be considered as entry barriers shielding the firms that possess the capabilities from those that do not. Holgersson et. al (2022) for example argues that certain activities may be considered complementary, which makes it beneficial for activities to be collected within the same entity to avoid holdups. Those actors that possess such combinations of capabilities may thus be better shielded for innovation within that field. Teece et. al (1997) furthermore emphasized how firms who possess dynamic capabilities, i.e. the possibility to adapt and relearn are more likely to survive in rapidly changing environments, for example when emerging technology that challenges current technologies arise in an industry. Teece et. al (1997) specifically points out benchmarking as a practice that may aid in the development of dynamic capabilities. This builds on the insight that a major threat to incumbent organizations is inwards-looking and the absence of monitoring market changes and adapting accordingly when the market landscape changes (Teece et. al, 1997; Carlgren et. al, 2016).

The theoretical considerations outlined emphasize that depending on strategic considerations a firm can select different IP strategies to protect an innovation including patenting, secrecy, publishing, or relying on market structure mechanisms. When performing a patent portfolio benchmark, it is important to consider that when a firm lags in terms of patent portfolio value, it does not necessarily mean that the firm has not made R&D investments. For the thesis scope despite publishing or secrecy activities, the incorporation of this body of literature supported the analysis of the benchmark results considering the complexity of the innovation process in the industry context. Patent information, however, is public and systemized which provides an opportunity for firms to benchmark against competitors.

2.2.6. Patenting activity in the aerospace industry

Patents are generally applied to industries where R&D costs are high but imitation costs are low, where the disclosed information does not give competitors new innovative opportunities to a large degree, and when innovation is cumulative or builds on other fragments of knowledge that are controlled by other parties (Orzenigo and Sterzi, 2010).

Generally, compared to other industries, the patenting activity in the aerospace industry is low, whereas other means of protection such as safety certifications, trade secrets, and design and manufacturing capabilities are used to a larger extent as more important means of protection than patents (Elkington, 2012).

2.3 Patent valuation methods for strategic purposes

Patent valuation for strategic purposes generally assesses the elements of a patent that constitute value, and sometimes also incorporates strategic insights such as the ones mentioned in the previous chapters. However, the elements assessed differ from method to method. This section summarizes which patent value drivers have been taken into consideration in previous literature. Indexes that represent the main different approaches in the academic literature will be presented in chronological order. A general distinction in the patent valuation literature is between quantitative and qualitative approaches to the value of a patent (Girgin Kalıp et al., 2022; Lagrost et. al, 2010). The majority of the methods in the body of literature have in turn been quantitative where the mix of the two approaches is a recent addition to the field.

One of the first studies in the area of patent benchmarking was developed by Ginarte and Park (1997). The study proposes that the strength of patent protection can be measured by analyzing the patent mainly through its legal characteristics. The proposed value index considers five aspects: market size, membership of international treaties (e.g. WIPO application), enforcement mechanisms (litigation or opposition occurrences and outcomes), and restrictions on patent rights and duration of patent protection.

Lanjouw and Schankerman (2004) presented another valuation method with a set of other metrics in an index called The Patent Quality Index, which analyzes the patent quality through the following indicators: number of claims, forward citations, number of backward citations, and family size. This index therefore focuses exclusively on the technological scope.

One of the most referenced indexes within the literature is The Patent Asset Index (PAI) developed by Ernst and Omland (2011), which measures the overall value of the patent portfolio providing an approach for benchmarking against competitors. The key indicators used to calculate the PAI are portfolio size which is defined as the number of granted and valid patents at a specific moment, including the number of patents under examination and published pending patent applications. It also considers the market size, as well as the technology relevance through a citation-based indicator that assesses the technological impact of patents, eliminating systematic distortions, which the authors point out, is a major problem of priorly proposed citation-based patent indicators. Ernst and Omland for example suggest patent age has to be taken into account. The authors argue that the competitive impact of the patent is determined by the combination of a patent's technology relevance and market coverage, calculated as the product of these two. Finally, the PAI is determined by the overall strength of a company's patent portfolio, calculated as the sum of the competitive impact of all active patents in the portfolio. van Zeebroeck (2011) furthermore developed a model that was also citation-based and considered the market size but also considered other factors. The valuation was based on forward citations, grant decisions, families, renewals, and oppositions. Those in favor of using only quantitative metrics such as the methods mentioned so far in the chapter argue it is the only way of valuing a patent scientifically (Lagrost et. al, 2010).

The previously mentioned patent valuation indexes are all quantitative, and do not capture qualitative strategic factors that impact the patent value. A common critique of only using quantitative metrics and not incorporating qualitative considerations is that it neglects the complete valuation of patents in terms of factors that cannot be measured directly through the patent information (Lagrost et. al, 2010). In addition, it has been emphasized by e.g. Pargaonkar (2016) that IP competitive intelligence is more effective when insights from the patent landscape are reconciled with the internal strategic objectives.

One index that captures internal strategic objectives in the valuation process is the index identified by Grimaldi et. al (2018). The index is called the Patent Portfolio Value Index (PPVI) and uses both quantitative and qualitative metrics. It in turn provides a quantitative score by quantifying the qualitative metrics. The PPVI thus to some degree provides a systematic approach to this gap in the literature by combining both dimensions and considering the perceptions and judgments of decision makers.

The PPVI is based on the five determinants selected for their importance to the patents' value: claims, forward citations, market coverage, strategic positioning, and economic importance. This index provides a supportive tool for managers to assess the value of patent portfolios according to internal capabilities and strategic positioning (Grimaldi et. al, 2018). The framework quantifies previously qualitative data, which is favorable for a standardized benchmarking approach, but has an internal perspective requiring the judgments of managers for every company assessed and is therefore not coherent with a benchmarking approach.

Cricelli et. al (2021) proposed a new framework that similar to the PPVI reconciles the quantitative and qualitative metrics. The framework analyzes patent value across multiple dimensions which according to the authors provides a more holistic view of a patent portfolio. Secondly, the methodology departs from the aim of creating alignment between the patent portfolio and the corporate strategy, ensuring that patents contribute effectively to business objectives. This is for example done through setting weights to the metrics within the index, which is a way of aligning the metrics with the overall strategic goals. How these weights are assigned is in turn mentioned as a critical aspect of the valuation framework (Cricelli et. al, 2021). The assignation can be made in a few different ways. Zhang et, al (2017) for example suggests a structured process for this in terms of either a Delphi method or using an Analytical Hierarchy Process (AHP). The AHP method is also suggested by Cricelli et. al (2021).

The same authors furthermore consider a range of different aspects in the PPVI, including legal capacity, innovative capacity, market opportunities, strategic alignment, and financial contribution of patents, offering a more comprehensive evaluation approach compared to previous methodologies that may focus on a subset of these dimensions. Furthermore, by ranking patents based on their strategic value and market potential, the authors argue that companies can identify core patents that provide a competitive advantage and prioritize protection and exploitation strategies based on the patent ranking.

The framework is not, however, applied for the purpose of benchmarking. Instead, the authors focus on patent portfolio internal valuation. The inclusion of the financial and some strategic metrics is the main obstacle to conducting a benchmarking approach requiring internal data for each benchmarked company. In addition, the authors emphasize the importance of selecting metrics based on technological, market, and strategic considerations without providing a transparent process. Finally, the authors proposed 44 value indicators which is a major difference from previous models, for example, compared to the 5 dimensions and 2 dimensions proposed by Grimaldi et. al (2018) and Ernst and Omland (2011) respectively. Despite providing a more complete final score it might not be feasible for managers to set weights to all the 44 different impact categories. Furthermore, the empirical evidence for some of the used metrics in the PPVI is lower than others used (Girgin Kalıp et al., 2022), which may enable a reduction to fewer factors, while still capturing a holistic view.

2.4. Patent portfolio management

To take action upon the patent portfolio benchmarking the patent portfolio management literature supports the analysis of benchmarking results and turns them into strategic insights in regard to IP strategy.

The framework developed by Grimaldi et. al, (2015) uses a combination of qualitative and quantitative criteria to assess the value of patent portfolios. It considers factors such as technical scope, forward citation frequency, market coverage, patenting strategy, and economic relevance. This allows companies to gain a deep understanding of their patent portfolios and make strategic decisions based on the perceived value of the patents. By analyzing these criteria, companies can identify the strengths and weaknesses of their patents, decide on selling or keeping patents, and evaluate the modalities of negotiating license agreements with partners. This helps in balancing the patent portfolio and taking appropriate strategic measures. The author emphasizes the importance of integrating the technological and bibliometric factors with the strategic-economic perspective to guide decision making.

Pargaonkar (2016), provides a framework for patent landscaping and IP competitive intelligence which requires the following elements: a robust process for continuous revision, proper technology for search, analysis, and repository, and finally, a skilled team with interdisciplinary knowledge in IP. Patent landscape and IP competitive intelligence can be described as anticipatory prescriptive analysis. This involves understanding and anticipating the competitive environment within which a company operates. Pargaonkar (2016) explains that for an effective competitive intelligence report, it is necessary to convert data into information that through interpretation will turn into intelligence. Depending on the level of analysis done and the resources invested, more correlations and insights can be taken from the assessment. There are differences between ad hoc patent analysis and full-time IP competitive intelligence.

Ad hoc patent analysis is more focused on immediate needs, while IP competitive intelligence is strategic and deliberate. Full-time IP competitive intelligence requires dedicated personnel committed to the task. IP competitive intelligence is more effective when aligned with senior IP management, corporate, technology, or strategic planning. Additionally, having experienced patent analysts or highly skilled IP competitive intelligence managers is essential for effective IP competitive intelligence. A robust IP competitive technical intelligence community of practice can include various professionals such as patent attorneys, technologists, finance, marketing, and strategy executives. There is an opportunity for patent information professionals to promote the strategic use of IP competitive intelligence. Pargaonkar (2016) argues that allocating full-time IP competitive intelligence personnel and developing a dedicated capability can benefit almost every company. Strategic intent and usage of the information are key drivers for effective IP competitive intelligence.

Furthermore, the management of patent portfolios and how certain patents are used can impact the relationships between actors within an ecosystem. Azzam et. al (2017) for example presented a case study of how Thales Alenia Space (TAS) used a licensing strategy to help stabilize its ecosystem of SME partners. By allowing SMEs to commercialize TAS's patented technologies in non-aerospace markets, TAS was able to diversify the revenue streams of these vulnerable partners and reduce their dependence on TAS. This allowed SMEs to leverage these technologies in new markets, rather than being limited to aerospace applications enabling patent portfolio value optimization. The article notes that TAS's patent licensing was motivated more by value creation (stabilizing the ecosystem) than pure value appropriation. This suggests companies may want to balance these two objectives, rather than focusing solely on maximizing royalties or protecting exclusivity. Overall, the TAS case provides a model for how an aerospace company can strategically manage its patent portfolio to orchestrate a more stable and resilient business ecosystem, an increasingly important consideration in complex, technology-driven industries (Azzam et. al, 2017).

3. Method

This section will explain the methodical choices made in the thesis, how the data was collected and analyzed, and how the trustworthiness of the findings of the thesis can be assessed.

3.1. Research design and methodology

According to Bell et. al (2022), two main distinctions in research design can be made, either it can be made qualitatively or quantitatively. In this study, both quantitative and qualitative approaches have been used to aid in answering different parts of the research questions. Quantitative research is largely characterized by counting and measuring and aims to maintain a high level of objectivity (Bell et. al, 2022). Qualitative research on the other hand focuses on depth and on understanding a certain phenomenon in detail (Bell et. al, 2022).

Establishing contextual factors and reviewing metrics to be included in the patent valuation index was done based on qualitative research methods. More specifically, a literature review and interviews were conducted. Furthermore, a patent search was conducted, where interviews aided in understanding which different CPC codes and terms could capture the relevant patents for the technology. The patent benchmarking in turn included quantitative elements in terms of collection of patent data and calculation of patent value scores based on that patent data collection. Moreover, the results analysis is done in a quantitative manner having an index score providing a source of comparison between portfolios.

Furthermore, research can be described as either deductive or inductive (Bell et. al, 2022). Deductive research means hypotheses are formulated from available theory and that these hypotheses are tested through studies of reality (Bell et. al, 2022). Inductive research on the other hand means doing observations of reality and in turn formulating generalizations of that reality (Bell et. al, 2022). Abductive research is when the researcher combines both an inductive and deductive approach interchangeably (Bell et. al, 2022). The method used in this thesis can be described as abductive, as the case study entailed insights into how a patent valuation index can be adapted to the considerations of, in this case, a certain company benchmarking their positioning within AM in the aerospace industry and produce a discussion around that connected to the existing literature on patent benchmarking, and available metrics. However, it has also used a deductive approach, as the current theory has been reviewed through a literature review that in turn has been the basis for selecting metrics and formulating interview questions.

The main methods used, which data was collected from the methods, and the consequent data analysis and treatment are summarized in Table 2. A more detailed discussion around the methods will be described in the following chapters.

Method	Data collected	Data analysis/treatment
Literature review	Metrics research, interview guide development, technology contextualization	Coding (recurring themes)
Semi-structured interviews	Firm, industry and technology understanding	Identifying similarities/differences, coding based on notes from interviews in close connection to interview
Patent search	Patent data for benchmarking	Data treatment and sensitivity analysis in Excel

Table 2. Description of the methods used for data collection.

3.2. Data collection methods

For this thesis, three main data collection methods have been used, a literature review, interviews, and collection of patent data. The following section will explain what data was collected with each respective collection method and how the data collection was performed.

3.2.1. Literature review

The literature review was used to identify the possible metrics within the patent valuation literature and to establish the empirical and theoretical arguments for using these metrics. It was also used to identify contextual factors in patenting activity. Furthermore, it was used to formulate interview guides.

The literature review was performed using search words such as “patent valuation”, “patent benchmarking”, “intellectual property valuation” and “IP valuation”, mainly in the database Scopus, but also in Google Scholar. This rendered articles discussing different valuation approaches of patents. The references of those articles were in turn used for further collection of theory on patent valuation and metrics. A literature review was also done to understand additive manufacturing as a technology. This review included scientific articles about the technology which were found in Scopus similarly to the patent valuation searches, where both general articles on additive manufacturing, as well as the technology applied in the aerospace context were reviewed. Additionally, two books on additive manufacturing were used to provide a general foundation within the technology. When selecting articles to include in the thesis two main considerations were considered, first the relevancy of the topic treated in the article and secondly the number of citations the article had received. Some articles with fewer citations were included if they were written more recently.

3.2.2. Interviews

The interviews were used to define contextual factors within the industry, for the firm and technology. Additionally, they were used for the inductive aspects of the research design, i.e., contrasting the findings of the literature review and subsequently identifying and assigning importance to the metrics identified in the literature review. Interviews also aided in the patent search, by establishing terms to be used in the querying for capturing patents relevant to the case company’s operations within additive manufacturing in terms of CPC codes and terms.

Choices were also made regarding how the interviews were conducted. Interviews can be classified as either structured, semi-structured, or unstructured (Bell et. al, 2022).

Since the interviews have aimed to understand the context of the case company, industry, and technology in great detail, the interviews have been of a semi-structured and unstructured form, since these have the benefit of probing the questions in light of what is uncovered during the interviews (Bell et. al, 2022).

The first interviews were conducted in a more unstructured way to explore the topics more freely and provide insights useful firstly in defining the problem formulation, and further formulating consecutive more structured interview guides, where topics needing further exploration were treated. This is aligned with a theoretical sampling approach where the basis for exploration revolves around theoretical findings (Bell et. al, 2022). For the AM interviews, for example, the first interview revolved around understanding the technology in more detail, which applications mainly were developed within the industry and company.

Regarding sampling, Bell et. al (2022) argue that for qualitative research, the research questions can guide which people to interview, where the selection of people is based on a purposive approach aiming at answering the research questions. That has therefore also been the sampling strategy in this thesis.

Furthermore, the interviewee sampling has been done to attain a broad range of perspectives helpful for adequately answering the research questions, which is also argued for by Bell et. al (2022). This was thus also the premise for setting the sampling size in this thesis. The interviewees ranged from people within AM engineering, IP management, and IP strategy. Additionally, access to the interviewees was made possible through a champion within the IP department with good insight into the organizational structure of the case company. Table 3 summarizes the interviews conducted during the thesis.

Interviewee	Topic	Date	Duration
R&D manager	Explorative interview, IP process	30/1 2024	60 min
Head of IP	IP strategy	14/2 2024	60 min
IP manager	IP strategy	22/2 2024	60 min
AM engineer	Explorative interview, AM technology	26/3 2024	60 min
AM engineer	AM technology	3/4 2024	85 min
Customer strategy director	Industry dynamics and the importance of IP	4/4 2024	60 min
R&D manager	Industry dynamics and the importance of IP	12/4 2024	60 min

Table 3. The interviews conducted and the roles of the interviewees at the case company.

In addition to the interviews, qualitative data has been gathered continuously by close communication with two IP engineers at the case company. One example was the guidance provided when selecting the actors to benchmark against, which will be elaborated on further in the following chapter.

3.2.3. Patent search

The patent search was in turn conducted to collect the patent data from the actors and to use it as input for the patent valuation index, which had been established through the literature review and interviews as described in previous sections. This in turn enabled the benchmarking among the actors within the industry to be done.

The first step of the patent search was to define which companies to include in the search. Here, actors on all steps of the value chain (see section 4.1. The aerospace industry for a description of the value chain) were included since this study includes an ecosystem perspective, aiming at understanding how the relations may be impacted by the development of AM. The specific companies included were selected partly based on internal interviews at the case company and partly based on a complementary landscaping search done to include additional companies in the sector not mentioned by the case company. The aim was to have several companies at all steps of the value chain to be able to conduct an analysis on a tier level. A complete list of the companies included in the patent search is featured below in Table 4:

Tier	Company	Number of employees (approx.)	Patent families within AM (approx.)
Aircraft Original Equipment Manufacturers	Boeing Co.	170 000	145
	Airbus Group SAS	125 000	100
System providers	RTX	185 000	236
	General Electric Company	168 000	280
	Rolls-Royce Holdings Plc	50 000	94
	Safran S.A.	92 000	150
First-tier suppliers	MTU Holdings Inc	11 000	9
	Melrose Industries PLC	15 000	7
	Spirit AeroSystems	18 000	3
	KHI	34 000	11

	Hanwha Group	43 000	16
	IHI Corporation	26 000	28
	MHI Machinery System Co., Ltd.	77 000	71
Component suppliers	Barnes Group Inc.	5 000	1
	Sequa Corp	100	1
Casting and forging houses	Howmet Aerospace, Inc.	23 000	6
	Carlyle Group LP	2 000	1
	Aubert & Duval	4 000	1
	Arconic Inc.	11 600	13
	Norsk Titanium As	100	9
	Berkshire Hathaway Inc	396 500	24

Table 4. The companies included in the patent search.

It can be noted that only two component suppliers are included in the benchmarking. This is a consequence of not existing patents for the other actors within that tier. Additionally, for those two included, one patent family was found each. These two are included anyway since also the low number of patents in certain tiers is considered a finding.

To acquire the necessary data for the patent benchmarking, two software were used, Cipher and Patseer. Firstly, Cipher was used to get all the patent numbers for each company respectively, and to only capture the patents within additive manufacturing a query was defined. The query was defined based on initial interviews at the case company where keywords for the technology were detected in combination with keywords from the literature review on the technology as well as going through a list of patents provided by the case company and reading them through to detect keywords. The resulting query consisted of a combination of words that had to be included and defining several CPC codes of which at least one had to be included within the patent that are commonly used for the additive manufacturing technology concerning the case company's operations:

title_abstract_claims: *((metal OR alloy) AND (deposit* OR layer*)) AND cpc_code:(B22F OR B23K OR B33Y OR B28B OR B29C OR B29L OR B29K)*

The query was a result of testing back and forth, where a validity check was done by firstly, establishing that all the patents already provided by the case company were detected through the query, and secondly by conferring with an experienced IP engineer at the case company. The querying was then applied to all companies in Table 4, after which a filter for only including patents that had been granted was applied, and filtering away expired patents. Additionally, the search was made on a patent family basis to not analyze patents within the same family several times since these contain the same underlying information for the patent valuation, which should only be taken into account once for the valuation. This way a complete list of patents within additive manufacturing from Cipher from the 21 companies included in the sample was obtained, totaling 1235 patents. Since Patseer includes other, additional data points than Cipher, the list of patents was inputted into Patseer to obtain necessary data points for conducting the benchmarking.

3.3. Data analysis

In this section, the data analysis connected to the literature review, interviews, and patent search will be elaborated on.

3.3.1. Literature review

Coding was used as an analytical tool to get an overview of recurring patterns in the body of literature. Coding can be described as a tool for interpreting qualitative data and sorting similar information into defined concepts, or codes (Bell et. al, 2022). Regarding the metrics, it was at an early stage noticed that the valuation of patents, can be done quantitatively, qualitatively, or by mixing the two approaches by using quantitative metrics and quantifying qualitative metrics providing an operationalization of the results to complement the index with more aspects. The reviewed articles on patent valuation were therefore sorted into these three different categories, and the arguments for using one approach over the other were outlined. Having done the literature review and coding into their respective themes together with initial interviews at the case company, it was established that the mix of quantitative and qualitative approaches for patent valuation would capture the most holistic view of the patent value. Therefore, the literature devoted to that specific research field was used to a larger degree for further definition of a valuation index.

Furthermore, studies analyze patent value indicators and their explanatory power in different contexts concerning industries. Therefore, the findings were structured into the industry context to get an overview of possible similarities with the context of this case study, the development of additive manufacturing within the aerospace industry. The literature also revealed themes around firm, technology, and industry specific reasons to patent, which was an insight that led us to formulate the questions in the interview guides to acquire firm, industry, and technology specific information from the interviewees to explore how those considerations could be taken into account in the formulation of a valuation index.

3.3.2. Interviews

To ensure that the analysis of the interviews could be done at a later stage and also contrasted with the literature, detailed notes were taken during the interviews. A thematic content analysis approach was then mainly used to make sense of the findings, by noticing common themes and differences across the interviews (Bell et. al, 2022). This approach was however mostly used for the interviews that were conducted with people with similar roles at the company, such as the R&D manager and the customer strategy director, since questions and topics were reused in those interviews.

3.3.3. Patent search

The data processing from the patent search was performed in Excel. In the initial data analysis step, errors in the data were detected and corrected. Some patent numbers contained mismatches between Cipher and Patseer and were thus corrected, to be able to associate the two data sources with each other. Furthermore, some patents were excluded due to missing data on the main CPC code, however, this should not affect the overall result significantly since these patents were present for companies with an already large sample of patents. This step led to the exclusion of 29 patents, totaling 1206 patents, the distribution of these among the companies can be seen in Figure 1.

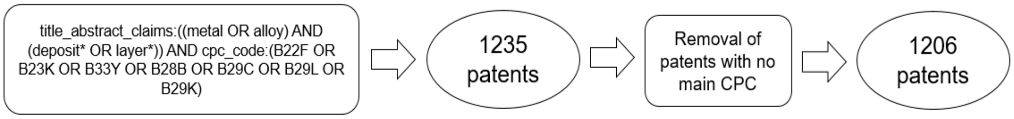

Figure 1. Summary of the resulting patents from the patent search and data treatment.

Once the patent data had been collected, the metrics calculations for the index were implemented in Excel. The formulas for the individual metrics however rendered values that were not comparable in size. Therefore, it was desirable to rescale the individual scores into a range between [0,1]. To check the possibility of doing this, the distribution of the scores was first checked, where it was found some of the metrics approximated a normal distribution, whereas others followed other distributions. Using the min-max method for normalization made it possible to fit the data within the desired range of [0,1], while keeping the variation within the scores and without putting any requirements on the same distribution among the metrics (Galias, 2009).

3.3.4. Sensitivity analysis

Sensitivity analysis supported the understanding of the impact of varying input parameters on the model's results. This allows for assessing the robustness of the index under different conditions and identifying critical factors. The process involved testing the model with and without the main source of uncertainty. The analysis provided insights into which parameters contribute most significantly to the overall uncertainty.

3.4. Trustworthiness of findings

In the evaluation of findings, different criteria are used for qualitative and quantitative research (Bell et. al, 2022). In qualitative research, Bell et. al (2022) suggest evaluating the credibility, transferability, dependability and confirmability of the findings. These criteria will therefore be discussed in the following section.

3.4.1. Credibility

Credibility can be described as the extent to which different researchers would arrive at different descriptions from studying the same social reality (Bell et. al, 2022). A way of counteracting this is to use respondent validation, for example by letting the respondents take part in the researcher's account and have them validate its accuracy (Bell et. al, 2022). Respondent validation has therefore been used throughout this thesis through continuous communication with IP engineers and letting an IP manager validate the findings.

Additionally, within the body of literature on patent valuation there are two different stances on patent valuation. Those that consider quantifiable metrics the only scientific method, whereas others argue quantifiable metrics cannot capture the entire value of a patent (Girgin Kalip et. al, 2022; Lagrost et. al, 2010). The authors of this thesis have a background in industrial engineering and management and may therefore be influenced in favor of the qualitative stance to a larger degree than authors with a purely quantitative background would. It has therefore been important for the authors to conduct a thorough literature review, which has resulted in the insight that there is no one true stance on how patent valuation should be done.

This thesis aims to be transparent with the approach to which the valuation framework has been outlined to reflect the social reality that has been studied as transparently as possible, and thus enable the reader to understand how the description presented in this thesis was reached.

3.4.2. Transferability

A main feature of qualitative research is the focus on depth rather than breadth (Bell et. al, 2022). Transferability therefore aims at evaluating the extent to which the researcher gives rich descriptions regarding the context that has been studied so that others can make judgments on its generalizability (Bell et. al, 2022). In this study, the chapter "Context of the study" aims to give background to both the case company and the industry for the reader to be able to understand under which circumstances the study was conducted, additionally, the method section has aimed at giving a transparent description to the different considerations in the data collection.

3.4.3. Dependability

Another consideration is to which extent the researcher documents the research process so that it is possible to easily establish which findings and underlying documentation the researcher concludes (Bell et. al, 2022). In this thesis, consideration has been taken to this by keeping extensive notes of interviews and discussions. Recording the interviews has, however, not been possible in the thesis. The extensive notes and consistent respondent validation have however been tools that have benefited the dependability despite this.

3.4.4. Confirmability

Confirmability has to do with the degree to which the collected data and following analysis are done without being affected by the researchers' own beliefs and personal biases (Bell et. al, 2022). Several measures have been taken to ensure confirmability during this thesis. The design with unstructured interviews, freely exploring topics based on the discussions from company employees, and after that formulating more structured interview guides is one such consideration. Another one was to do an extensive literature review before formulating interview guides in order to decrease the risk of being biased by personal assumptions.

4. Context of the study

This section aims to highlight the scope under which the thesis has been conducted. This enables the reader to establish to what degree findings are generalizable in other settings. Additionally, it provides context for understanding the results and following the discussion of the findings.

4.1. The aerospace industry[1]

This thesis revolves around a case study design within the aerospace industry. In the following chapter industry characteristics of that sector will be highlighted. This

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[1] Information regarding the commercial aircraft engine industry was collected from two interviews with the customer strategy director (2024) and the R&D department manager (2024)

section supports adapting the metrics to the aerospace industry and providing background to the case study.

The aerospace industry is characterized by high capital requirements with long product lifecycles which require the engagement of multiple suppliers and partners in the development and commercialization phases of the technology. This is especially the case for engine manufacturing where the cycle from product development to the end of aftermarket activities reaches about 50 years, for the structures the manufacturing processes may be shorter but the lifecycles are still long (Customer strategy director, 4/4 2024). The product development phase is characterized by different TRLs (Technology Readiness Levels) comprising concept development, design, manufacturing, testing and culminating in a commercialization phase. The TRLs, developed by NASA are used to describe system maturity and have become a recognizable element of the development of technologies for future products in the aerospace and defense sectors (Ward et. al, 2021).

The aerospace industry actors are engaged in strategic partnerships and alliances allowing for collaboration and competition solutions depending on the market scenario (Ritala et. al 2013). The value chain comprises many actors on different tiers participating in the development of the aircraft (Mocenco, 2015). The past years were characterized by prime contractors reducing the size of their supply chains and mergers and acquisitions of knowledgeable suppliers with technical superior capabilities (Smith and Tranfield, 2005). The aerospace industry works with a collaborative model of Risk-Sharing Partnerships (RSP) which is mainly adopted between system providers and first-tier suppliers. This model quantifies the degree of the outsourced activity and correspondent economic model resulting in the type and level of risk shared between the buyer and the supplier (Wagner, 2015). This relationship is a consequence of the high development costs for developing especially engines, and thus wanting to share the risks in-between several parties (Johansson, 2013). Below in Table 5, the tier configuration as well as important actors within the industry are depicted based on the interviews with the case company:

Tier	Companies	Role in the value chain
Aircraft Original Equipment Manufacturers	Boeing Co.	Responsible for assembling large aircraft components and providing the end product to the customers. The aircraft OEMs provide design, development and manufacturing capabilities, before the product is tested and delivered to the customer.
	Airbus Group SAS	
	RTX[2]	System providers supply major sections of the aircraft systems

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[2] RTX is the mother company of Collins Aerospace, Pratt & Whitney and Rayethon (RTX, 2024)

System providers	General Electric Company[3]	to the aircraft OEMs including engines, avionics, aircraft interior and landing gear.
	Rolls-Royce Holdings Plc	
	Safran S.A.	
First-tier suppliers	MTU Holdings Inc	Has the closest touch point with the system providers, with which they negotiate directly. The system providers use several first-tier suppliers for different parts of the development.
	Melrose Industries PLC	
	Spirit AeroSystems	
	Kawasaki Heavy Industries	
	Hanwha Group	
	IHI Corporation	
	Mitsubishi Heavy Industries Ltd.	
Component suppliers	Barnes Group Inc.	The component suppliers, also called second-tier suppliers, supply the first tier and are frequently small and medium-sized companies that provide complex manufacturing products.
	Sequa Corp[4]	
Casting and forging houses	Howmet Aerospace, Inc.	Supplies castings and forgings to other parts of the value chain. They have a niche but valuable role in the value chain.
	Carlyle Group LP	
	Aubert & Duval	
	Arconic Inc.	
	Norsk Titanium As	
	Berkshire Hathaway Inc[5]	

Table 5. Aerospace tier structure and important companies within the industry

As displayed in Table 5, the aerospace industry can be segmented according to a tier setup. Generally, each tier has different capabilities because of the different operations performed in different parts of the value chain (R&D manager interview, 2024). The

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[3] General Electric operates in many businesses apart from aerospace. Their subsidiaries within aerospace is GE Aerospace and GE Aerospace Research. They also have a subsidiary specialized on only AM, GE Additive.

[4] Sequa corp is the holding company of Chromalloy

[5] Berkshire Hathaway operates in several industries, but owns one of the most profitable casting/forging houses for the aerospace industry in terms of their subsidiary PCC

aircraft OEMs own the system integration process and are thus responsible for selecting the industry standards and have high bargaining power compared to the other actors in the ecosystem. The major actors, Boeing and Airbus, have significant power in the selection of aircraft systems. The system providers take ownership of system development and have great design capabilities. They also collaborate directly with multiple first-tier suppliers at the same time, resulting in high bargaining power for the downstream parts of the supply chain. The first-tier supplier establishes strategic partnerships with the systems integrators and specializes in specific parts of the product, such as engines, avionics, aircraft interior, and landing gear, which results in highly developed manufacturing and design capabilities overlapping with the system integrators' capabilities to some extent.

Within the tiers of aircraft OEMs, system providers, and first-tier suppliers complying with safety regulations, acquiring safety certifications for products, and doing extensive testing of components are also important capabilities for operating within those downstream parts of the value chain. The component suppliers are seen as pure suppliers and have less impact on the product development phase. This tier has low bargaining power and is specialized in the manufacturing process. The casting and forging houses supply casting and forgings making them knowledgeable in an important niche within the industry, but that does not require as complex and extensive capabilities as for the tiers downstream close to the end customer.

Overall, this ecosystem perspective highlights the complexity of the industry incorporating collaboration and competition dynamics between and within tiers. The bargaining power in terms of components and processes used is highly dependent on the aircraft OEMs.

4.2. The case company[6]

This section will describe the case company and provide context as to where the case study was conducted.

The case study was conducted at a company within aerospace, which operates at the first-tier supplier level to system providers. The company has multinational coverage, with manufacturing facilities in more than 10 countries, 15000+ employees, and serves most of the world’s aircraft and engine manufacturers. The relationship with the customer and capabilities required in turn vary depending on the product supplied and the customer segment. The company acts as a strategic partner, component supplier, and aftermarket services provider.

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[6] Information regarding the organization structure and the IP strategy was collected from interviews with the head of IP, the R&D department manager and the customer strategy director

For this case, the study was conducted at an R&D department, which the IP team at the site was part of. This in turn influenced the contacts we had within the organization. During the study, the supervision was conducted by an IP engineer at the company. Although the IP team is spread out globally on different locations the IP strategy is set at a global level to the different business lines.

4.2.1. Patent management

The case company has an established patent process for protecting its technological developments which takes place at several steps in the organization. The process starts with the individual inventor sending in their innovations to the IP department. The documentation from the inventors is in turn reviewed and complemented as necessary by the IP department through a dialogue with the inventor. Here, the patentability of the innovation is determined. The patenting decision is then guided by input from managers and more centralized decision-makers in the organization. The output of this process could result in a patent, trade secret, know-how, or defensive publication. The overall mission of the IP department is to guide inventors in technology development protection through inventors' support and top managers' advisory on the selection of means of protection.

The strategy concerning patenting has the purpose of being aligned with the overall strategy of the company defined at a top management level. The priorities expected to be achieved with the patenting activity are (Customer strategy director, 4/4 2024; R&D manager, 12/4, 2024):

1. Secure freedom to operate
2. Increase bargaining power for collaborative R&D projects
3. Reflect a high-tech image
4. Enhance shareholder value
5. Motivate innovation
6. Sell/buy licenses

The three most prioritized motivations for patenting are described in the following section. The freedom to operate provides a defensive use of the patent to block others from blocking them. In the aerospace industry, technology lifetimes are long and require high investments, to pay off the development phase the product needs to be commercialized. Patent activity is expected to provide adequate means of protection to block competitors from commercialization. In this case, the company can make use of the technology with the possibility of suing others in case of infringement.

The second most important purpose of the patenting activity is to increase bargaining power for collaborative R&D projects. A great deal of the contracts is done through joint development work. In the context of the aerospace industry, partnering is essential to achieve a higher share in each contract. Hence the use of patents provides significant bargaining power for collaborative R&D projects and also facilitates knowledge-sharing in the project themselves. Patent activity is seen as an instrument to achieve their share and relevance in specific joint projects and technologies.

Finally, the patenting activity provides visibility on technology development which in the case company is seen as relevant for government funds application and credibility purposes among the company customers. Thus, the focus is on ensuring that the company can pursue innovation within the aerospace industry and develop the best products on the market to maintain and attract new development contracts with their customers (Head of IP, 14/2 2024).

4.2.2. Additive manufacturing development

AM has the potential to lower the cost base for the case company. Additionally, it would entail the possibility of producing more lightweight components than is the case today where large castings and forgings are used, which lead to large amounts of material waste. Additive manufacturing could thus majorly improve operations concerning sustainability for the case company (Customer strategy director, 4/4 2024).

Consequently, additive manufacturing has been a surging trend in the industry and has also become a larger focus for the case company. The technology is still in a development phase with few products being produced entirely by AM processes. The case company is also highly dedicated to the research field working in collaboration with the academia to accelerate a larger implementation of AM in the aerospace industry.

4.3. Additive manufacturing

This chapter will elaborate on the definition of AM and its relation to current manufacturing techniques describing technology characteristics helpful in the benchmarking process.

4.3.1. Relation to traditional manufacturing techniques

The traditional technique of manufacturing objects is to use some sort of subtractive manufacturing process, where the material is milled or carved to form the final object. Additive manufacturing is instead a manufacturing technique that builds the end object layer by layer, and thus reduces waste and the need for tooling while entailing great design flexibility (Pose-Rodriguez et. al, 2020).

A traditional way of creating objects is casting, however, to give the material the desired properties, the casting often requires to be complemented using tooling such as hammers or rolling. This enables the manufacturer to give the new material the desired mechanical properties. This tooling, however, generally gives rise to a significant quantity of wasted material (Singhal, 2022).

Another related manufacturing technique is welding which revolves around fusing one or more parts, typically by applying heat (Singhal, 2022). That way welding enables smaller entities to be combined to create a bigger end-product. A challenge of AM is to manufacture big parts by applying the necessary techniques. Additionally, welding can be used to join smaller AM parts into bigger parts (Karayel & Bozkurt, 2020). Conventional welding heat sources (electron beam, plasma, arc, and laser) are used in metal AM, where melted and fused materials are drawn into a desired shape, size and structure. The welding and AM are comparable considering the similarities present in the material's heat source technique. In contrast to welding, which merges two semi-finished pieces to create a more complex product, AM creates a single component that can be utilized directly or subsequently connected to other components or welded (Singhal, 2022).

The AM technique varies in its exact process implementation, where incentives for modifying the process include enhancing machine productivity, enabling new materials to be processed as well as inventing around already existing patented processes (Gibson et al., 2015). Several concepts are being introduced in additive manufacturing which have been extensively used for welding and casting processes (Oliveira et. al, 2019). The knowledge developed by decades of research on welding metallurgy and technologies can be used to better understand the additive manufacturing process and the implications on the microstructural features of the produced parts, including the origin of internal defects (Oliveira et. al, 2019).

Thus, despite the existing differences between technologies, this process innovation can be seen as competence enhancing and making the aerospace industry incumbents more skilled to implement the AM techniques in the production of aerospace components, using Porter's (1989) typology, this could be described as creating an entry barrier for companies who do not possess that knowledge. Finally, theoretical evidence on AM compared to previous techniques used suggests that AM can largely substitute casting and forging.

4.3.2. The usage of patents in additive manufacturing development

Patent protection has played a large role for industrial companies in their development of AM (Bechtold, 2016). The patents filed within AM have concerned the additive manufacturing machinery, components within the machinery, manufacturing processes and products. Furthermore, patent protection can cover the raw materials, in terms of powders, filaments, liquids, or sheets (Bechtold, 2016). Trade secrets have also been important in the protection since additive manufacturing is a process technology (Bechtold, 2016). Prock et. al (2020) mentions that products produced with AM may not be patentable since they might be products that previously were produced with the same or minorly different composition but a different technique. For the product to be patentable the composition must be sufficiently different (Prock et. al, 2020).

The increased patenting activity in AM has also led to developments in the classification of the technology. The European Patent Office in collaboration with the US Patent and Trademark Office, developed a special CPC subclass for additive manufacturing (B33Y). This is intended to support the classification of the technology and future prior art search (Bechtold, 2016).

Furthermore, the technology is being developed and patented within several different sectors. The development of AM has for example been important within the aerospace, automotive, and medical industries (Najmon et. al, 2019; Gao et. al, 2016). The application of metal component manufacturing is also the focus within the automotive industry similar to the aerospace industry (Pederson et. al, 2023). The existence of multiple industries where the technology is being developed thus opens up licensing possibilities.

5. Results of the study

This section will present the results of the literature review findings in combination with the interview insights which were taken into consideration for the definition of the index and consequently the patent benchmarking.

5.1. Development of patent valuation index

The framework developed in this thesis revolves around methods for aligning the focal company’s strategic objectives of the patenting activity, with the benchmarking process. Similarly to e.g. Cricelli et al. (2021) it therefore incorporates a mix of qualitative and quantitative metrics.

The selection of metrics in this framework builds on a literature review of the theoretical and empirical arguments for using certain metrics, reducing the used metrics to the ones with strong evidence. Additionally, it enables alignment with industry, firm, and technology specific adaptations to incorporate also the qualitative value elements in a quantifiable way, recognizing the importance of a holistic assessment for benchmarking purposes. This ensures alignment with the patenting priorities expressed at the case company. By incorporating metrics such as licensing, the framework facilitates strategic considerations, empowering managers to make well-informed decisions, and capture elements that are important value drivers in choosing a patenting strategy (Holgersson & Wallin, 2017; Azzam et. al, 2017).

Moreover, weight setting is used since it allows managers to align patent valuation with business priorities (Grimaldi et. al, 2018; Zhang et. al, 2017), further enhancing the utility and relevance of the evaluation process. The proposed valuation framework is summarized in Figure 2 below. The steps in the framework will be explained step by step in the following sections.

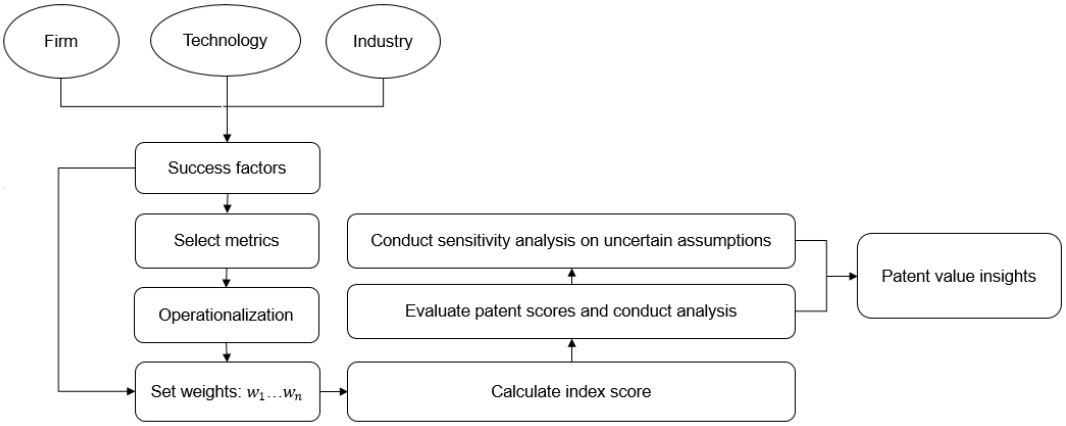

Figure 2. The proposed patent valuation process

5.1.1. Contextualizing: Firm, technology and industry

Through an analysis of the case context and the AM technology, the findings are summarized in this section and sorted by industry, firm, and technology:

- At an industry level it was found that the aerospace sector has a well-defined market structure with high entry barriers, and heavily dependent on collaborations through the risk-sharing partnership agreements with each industry tier providing a set of specific capabilities. Finally, design selection is highly dependent on aircraft OEMs.
- At a firm level, the case study company has a strategic position in the provision of system integrators which is sustained by the high quality of the products supplied (Customer strategy director, 4/4 2024). Additionally, the firm has a desire to develop AM technology (AM engineer, 26/3, 2024).
- At a technology level, AM in the aerospace context can be described as an emerging substitute technology for welding and casting. The process innovation can be classified as process enhancing. AM processes have applicability in multiple industries providing opportunities for licensing.

5.1.2. Success factors

To summarize the contextualization into clear factors, these considerations are summed into success factors. In this study context, the term success factor is used as a way of defining the kind of factors that contribute to a successful patenting strategy. The success factors were defined based on the case context dimensions: firm, industry and technology which synthesize the findings from the interviews and literature review.

Success factors from the firm perspective were based on interviews at the case company (see section 4.2.1. Patent management) and the most emphasized ones were freedom to operate and increasing the bargaining power for collaborative R&D projects.

Regarding industry factors, established partnerships and reputation within the business means actors are favored also for being included in future contracts, constituting a protection barrier. Furthermore, capabilities act as a barrier meaning certain actors in the value chain for example may lack experience in the extensive testing of components required for safety certifications.

On a technology level, it is desirable to not reveal more to the competitors than necessary, patents in turn reveal the innovation in great detail which might not be desirable for process technologies such as AM. Furthermore, AM is being developed across several industries and thus it opens for licensing opportunities, where the company may be able to license the innovation for other applications that do not interfere with the own business operations. Table 6 below summarizes these success factors, which are based on the interviews and literature review.

Perspective	Success factor
Firm	• Freedom to operate • Increase bargaining power for collaborative R&D projects • Technological superiority
Industry	• Capabilities acting as entry barriers • Established partnerships
Technology	• Not reveal processes to competitors if it is not necessary • Cross-industry applicability

Table 6. Summary of success factors from a firm, industry and technology perspective.

5.1.3. Metrics

The next part of the valuation process is to identify the metrics to be used in the index. The selection of metrics presented in this thesis builds on a literature review on patent valuation, where the theoretical and empirical argumentation for metrics has been reviewed, secondly, those metrics have been complemented with metrics that help align the patent benchmarking with important strategic considerations that also contribute to the patent value. A summary of the metrics selected and the basis for selection is summarized below in Table 7.

Metric	Theoretical	Empirical	Strategic alignment
Litigation	X	X	
Opposition	X	X	
Claims	X	X	
Forward citations	X	X	
Backward citations	X	X	

Substitute technology	X		X
Market size	X	X	X
Licensing	X		X
Value chain positioning	X		X
Sector trend	X		X
Patent investment	X		X

Table 7. The main motivation for including each metric in the patent valuation index.

In the following chapters the metrics will be described in greater detail, and the argumentation from a theoretical, empirical or strategic alignment perspective will be presented.

5.1.3.1. Legal factors

Legal factors reflect aspects of the patent regarding its legal strength. For the proposed index in this thesis, it includes the occurrence and outcome of litigation and opposition as well as the claims within the patent.

The litigation metric captures the historical analysis of survived and non-survived cases in litigation processes. The inclusion of this metric builds upon the empirical evidence that successful litigation outcomes reflect patent value positively (Girgin Kalıp et. al, 2022). The occurrence of litigation has furthermore been noted by some authors to be higher in emerging technological fields and where legal procedure is being challenged (Lanjouw & Schankerman, 2001).

For emerging technologies, those patents might also be faced with litigation to a higher degree than can be expected for more established technologies according to Lanjouw & Schankerman (2001). The litigation of a patent is furthermore expensive and means the scope for which the patent aims to protect is valuable enough to pursue costly legal actions (van Zeebroeck, 2011). Litigation occurrences were captured in a binary score as an adaptation to the formula proposed by Cricelli et. al (2021):

1: The patent family has been litigated and survived

0: The patent family has either not been litigated or was litigated but did not survive

Similar to the litigation metric, the opposition metric captures the number of raised issues against the grant of a patent by third parties and the output of the process, whether it survived or not. Opposing a patent is costly for the attacker, which implies that the attacker considers the patent valuable (Haroff et. al, 2003). Opposition as a value indicator for patents has been found to have empirical evidence in several studies, also with consideration to different industries (Girgin Kalıp et. al, 2022; Haroff et. al, 2003).

The possibility of succeeding with an opposition however differs between different sectors, where the pharmaceutical and chemical sectors often have water-tight patents, actors within those sectors therefore often do not oppose each other's patents to the same degree as in other sectors (Haroff et. al, 2003). The formula for capturing the opposition into the metric is similar to the litigation:

1: The patent family has been opposed and survived

0: The patent family has either not been opposed or was opposed but did not withstand the opposition

Another value indicator mentioned in the literature is the number of claims in a patent. This indicator has been found to positively correlate with the value of the patent as the number of claims increases (OuYang and Weng, 2011; Tong and Frame, 1994; Harrigan et al., 2017). Lanjouw and Schankerman (2001) observed that a large number of claims reflect the technological importance of the innovation embedded in the patent and its wide potential for profitability. Lerner (1994) and Shane (2001) pointed out that only highly valued patents, underpinned by several technical claims, make the company financial value increase.

Some authors furthermore argue for distinguishing between dependent and independent claims, but the empirical evidence suggests that the distinction has lower empirical evidence than looking at the number of claims collectively (Girgin Kalıp et. al, 2022). The number of claims has furthermore been argued to signal the scope of the patent (Beschorner, 2008; Denicolo, 1996). The formula for attributing a value to the number of claims used in the index is therefore:

$$\log(1 + \text{number of claims in patent})$$

5.1.3.2. Technological factors

Forward citations measure how many citations the patent in consideration has received. Authors have thus argued that this captures the patent's relevance for subsequent innovation (Ernst & Omland, 2011; Lanjouw & Schankerman, 2004; van Zeebroeck, 2011). This factor has empirical and theoretical validation in the literature review provided by (Girgin Kalıp et. al, 2022) and is also used in most of the available indexes, for example in the Patent Asset Index by Ernst & Omland (2011) and the one developed by Cricelli et. al (2021).

A problem with the metric is that it arises after the publication of the patent and therefore older patents will naturally have more forward citations than newer patents. It is therefore important to consider how to normalize the metric for patent age (Grimaldi, 2018; Ernst & Omland, 2011). Several authors including Caviggioli et. al (2013) as well as Cricelli et. al (2021) suggest the increase in patent value for the number of forward citations follows a logarithmic scale. Taking this into consideration, the value of the forward citations was captured by:

$$\frac{\log(1 + \text{number of forward citations})}{2025 - \text{PY}}$$

Where PY = patent publication year and 2025 represents the year of today (2024) + 1

Another type of citation revealed in a patent document is the number of backward citations. It measures the number of patent references to other patents in the patent document. The metric reflects the recognition of a patent within a specific technology and the progress made by prior research about the patent (Lanjouw & Schenkerman, 2004). For technologies that are more derivative in its nature, such as in mechanics and electronics, Lanjouw & Schenkerman (2004) found that backward citations reflected the patent value better than forward citations. The following formula was implemented for the backward citations:

$$\log(1 + \text{number of backward citations in patent})$$

The substitute technology metric reflects the potential of a patent to challenge the current products or techniques in the market. The metric has been suggested by Cricelli et. al (2021). Valuing patents that have the possibility of replacing old products or techniques might create incentives for firms to devote resources into radical rather than incremental innovation. It is known in the literature that incumbent firms often devote too few resources to radical innovation in favor of incremental innovation where revenue streams are more predictable, which in light of technology shifts lead to declining market shares (Carlgren et. al, 2016; March, 1991).

In the event of a substituting technology shift that enables cost reductions through process innovation, it would arguably be of major importance that the company invests as much or more in such technology to keep pace or preferably lie ahead of other actors. In light of this, the substitute technology metric captures such value for a patent. As it may be hard to determine the possibility for substitution on an individual patent basis, which is the approach taken by Cricelli et. al. (2021), we suggest determining the potential on a technology level, with a binary score:

> 1: The technology developed through the patent has the potential of substituting current technology
>
> 0: The technology developed through the patent does not have the potential of substituting current technology

5.1.3.3. Market factors

Market size, or market coverage, measures the number of countries in which the same invention has patent protection. Considering the costs to file in several jurisdictions, it signals belief in wide-spread commercial potential for the innovation (Harhoff et. al, 2003). Ernst & Omland (2011) emphasized that patent protection in all markets, however, should not be valued equally, since the demand for the technology or product may differ in different markets. Their suggestion is therefore to normalize according to the GDP of the country. Guellec & Van Pottelsberghe de la Potterie (2010) argue that patenting in many countries may indicate a lack of patenting strategy, and therefore signals less valuable patents, and therefore question the assumption that patent value strictly positively correlates with a larger family size.

Harhoff et. al (2003) furthermore found that geographic coverage was more important for products that had national markets such as drugs and chemicals, whereas it was less important for mechanical products and electronics. For the market size calculation, it is thus necessary to identify first the most important markets according to the technology and set weights for each. Secondly, it is suggested to specify the other less important markets. Depending on the relevance of national markets for the technology the weight setting for "others" can be defined. The formula for market size is therefore outlined in the following way:

$$\mathrm{MS}^{7} = \mathrm{M}_1 + \mathrm{M}_2 + \cdots + \mathrm{M}_\mathrm{n} + \mathrm{O} * \mathrm{W}$$

MS = Market size
M = score of each relevant market
O = number of other markets
W = standard score for other markets

The licensing metric captures the potential for a technology to have several applications enabling the owner to license it for other applications without interfering with the operability of the core business, this may be important since a major consideration to be done when faced with a licensing decision is whether or not the licensing would jeopardize the own economic rents (Katz & Shapiro, 1985).

If citations are used as a proxy for value, it is possible that licensing income could be missed. This was underlined by the lack of correlation between citation counts and licensing revenue studied by Sampat and Ziedonis (2007). As higher the potential to license a technology the higher the value. In this case, the analysis was performed on a technological level, and not on a patent level as proposed by Cricelli et. al (2021) due to similar considerations as for the substitute technology metric, the possibility for licensing is given on a binary scale:

---

[7] The score values are between 0-1, max of other markets score should be the difference between 1 and relevant markets sum score

1: The technology developed can be licensed without jeopardizing revenue streams from the core business

0: The technology developed cannot be licensed without jeopardizing revenue streams from the core business

Lastly, the value chain positioning metric captures the degree of overlapping capabilities between companies. This metric has not previously been quantified in the literature, but similarly to the substitution technology and licensing metrics, there is qualitative literature emphasizing the importance of considering this aspect in relation to patent value (Teece, 1997; Holgersson et. al, 2022), therefore our index incorporates this new metric. In relation to an ecosystem view it could be argued that the design and manufacturing capabilities of AM act as complements to each other, that in turn act as an additional barrier to vertical integration for e.g a firm in the forging/casting tier, making the patent investment for first-tier suppliers more valuable relative to forging and casting actors.

The approach requires selecting a focal company to benchmark against the other actors analyzed. For this analysis, the focal company corresponds to the case company. The analysis can be done as detailed as the valuation tool the user chooses, and an individual score can be given on a company basis. For this thesis, however, as it explores a certain technology and the development of it across an entire value chain and several tiers, the score was given on a tier level. Depending on the tier compared to, the capabilities might converge or diverge. As higher the convergence to the focal company capabilities the higher the value, since that would mean that the patent could be used for performing similar activities more easily. In this case, the analysis was performed on a firm level due to the dimensions of the dataset, and the qualitative assumptions were quantified in the following way and converted into numeric format:

1: Overlapping capabilities with the focal company

0.5: Partly overlapping capabilities with the focal company

0: Non-overlapping capabilities with the focal company

5.1.3.4. Strategy factors

The sector trend metric measures the increase in patenting during recent years within a specific technological field as defined by its main CPC on a sector level. Patents filed within a technological trend that has experienced a positive trend thus receive a higher score than those filed within technological fields where patenting activity has declined. The metric has been adopted from Cricelli et. al (2021):

$$\frac{\text{Number of patents in same main CPC as patent}\ {}'21\text{ to }{}'23 - \text{Number of patents in same main CPC as patent}\ {}'20\text{ to }{}'21}{\text{Number of patents in same main CPC as patent}\ {}'20\text{ to }{}'21}$$

The patent investment index measures the number of patents within a CPC class for the company divided by the total number of patents within that company for the same period. Thus, it quantifies how important the investment in the technological field is for the company. The formula adopted was provided by Cricelli et. al (2021):

$$\frac{\text{Number of patents in same main CPC within company as patent}\ {}'21\text{ to }{}'23}{\text{Total number of patents within company}\ {}'21\text{ to }{}'23}$$

5.1.4. Operationalization

Some of the metrics described in the previous section are qualitative metrics that are quantified by assigning a number from 0 to 1 to signal how the technology in question relates to that metric. Using operationalization builds on the concept of turning abstract concepts into measurable figures (Osorio et. al, 2019), the method is for example used by Cricelli et. al (2021) and also suggested by Lagrost et. al (2010) for patenting valuation purposes. The following chapter will describe how that assignment was applied to the specific context of this case study.

5.1.4.1. Substitute technology

The AM patents are filed since they enable improvements in the process regarding sustainability and cost-base compared to the current methods used according to the case company, not requiring as much material input, which could constitute a competitive advantage to the actors investing in it. Thus, for AM patents it is given a score of 1 in the index.

5.1.4.2. Market size

In the aerospace industry, considering the market coverage metric, components are used in integrated products, and it might be enough to patent in a few markets that are sufficiently important for the use, sale, and manufacturing of the end product. Only patenting in the US and EP might thus be sufficient patent protection for aerospace components since this is where the aircraft OEMs are located. Patent protection in those geographical markets is thus important. For these markets, the score attributed was 0.4 for each. Additive manufacturing could however to a larger degree have national markets, since it can be used for a wider range of products, especially for licensing purposes that could be valuable (Arora, 1997). Which in this case turned out to be given for each "other" market a classification of 0.05.

$$\mathrm{MS} = \mathrm{US} + \mathrm{EP} + \mathrm{O} * 0.05$$

Where patents filed in the US gives 0.4 and patents filed in the EP gives an additional 0.4.

5.1.4.3. Licensing

AM is a technology with proven potential in several industries, in terms of the biomedical and automotive industries (Gao et. al 2016). The fact that AM however spans over several industries opens up for licensing opportunities. The automotive industry for example largely builds upon manufacturing of larger structures of metal, much like the patents analyzed in this thesis within the aerospace industry, and licensing AM technology between the industries could thus be valuable, generating an additional stream of income. It has also been highlighted that innovation targeted at enabling additive manufacturing of larger scale components is a main area for the development of the technology in the future (AM engineer, 3/4 2024), which may be a particularly valuable field of innovation to patent and license between the aerospace and automotive industries. Thus, the AM patents are given a score of 1.

5.1.4.4. Value chain positioning

Throughout the literature, it is known that capabilities are dynamic to a certain degree (Teece et. al, 1997), and it is argued that incumbents need to be open to reconfiguring their capabilities when innovation emerges in order to capture the opportunities (Carlgren et. al, 2016; March, 1991). The aerospace industry is, however, heavily protected by its entry barriers in terms of safety certifications, which makes entrance by newcomers challenging. Also, within the industry, this poses a barrier to downstream integration. Actors upstream in the value chain may lack previous experience of safety testing and safety certification processes.

Additionally, it could be argued that the design and manufacturing capabilities of AM act as complements in the commercialization of AM. That in turn acts as an additional barrier to vertical integration. The value chain positioning indicator aims at capturing these considerations, the ease for a certain actor to get certain capabilities that challenge a focal company. In this case, the distinction was made on a tier-level where the following distinctions were made, see chapter 4.1. The aerospace industry for a description on the roles of the different tiers.

1: Overlapping capabilities (first-tier suppliers)

0.5: Partly overlapping (Aircraft OEMs and engine OEMs)

0: Not overlapping (forging/casting, component suppliers)

5.1.5. Weight setting

The attribution of weight to different parts of a valuation index implicitly means the decision-maker reflects upon the metrics used and which patent metrics constitute value (Grimaldi et. al, 2018). Furthermore, it can help align the patenting strategy with the strategic technological planning in a certain context, such as the one of AM in the aerospace industry (Grimaldi et. al, 2018). Cricelli et. al (2021) similarly argues that determining the weights to each metric and attributing more or less value should be done for the indexing purpose.

Actively setting weights and not letting the individual components such as many indexes suggest e.g. the PAI by Ernst & Omland (2011) be equal in weights was thus considered an important part of the understanding of patent value in the index development. Thus, weight setting incorporation was motivated by the need to align strategic considerations and also contextual differences depending on technology, firm and industry aspects. Actively setting weights enables understanding how these variations impact the patent final score. In this section, it will be explained how the weights were defined.

Weight setting reflects the success factors defined in the section 5.1.2. Success factors, and, consequently, will support the contextualization of the patent value. In a standard process the firm managers are responsible for selecting the success factors and then making a hierarchical analysis to decide which is the relative importance of each factor. For this case, the weight setting was done based on the interviews where the contextual motivation for weight setting is described in the table below:

Factors	Weight	Contextual motivation
Legal	15 %	Collaborative business model and high entry barriers
Technology	35 %	Technological superiority and increase bargaining power for collaborative R&D project contracts
Market	25 %	Potential for expanding technology application and the assessment of existing capabilities
Strategy	25 %	Internal relevance of the patent for firm and compared with the market context

Table 8. Summary of the assigned weight for each factor.

5.1.5.1. Legal factors

The first category considered was the legal aspect, which was given a score of 15%. In the majority of patent valuation methods, these factors are seen as a major aspect to determine the value of a patent. In this case, it is not considered as important as in other cases. This fact can be explained by the collaborative business model adopted by the entire value chain, the risk share revenue model (R&D manager interview, 2024). In addition, the strategy manager described the aerospace market structure as having high entry barriers and low risk of vertical integration in the sector (Customer strategy director interview, 2024). Both factors reduce the legal entropy in this sector and create a stable environment where litigation and opposition cases are outliers, but relevant to take into consideration.

However, considering that AM is an emerging technology, those patents might be faced with litigation to a higher degree than can be expected for more established technologies according to Lanjouw & Schankerman (2004). Given these considerations the three legal aspects considered were given the same score of 5%.

5.1.5.2. Technology factors

Among the four categories captured in the index, the technology aspect was given a score of 35%. In the case of aerospace, the focus on high technology developments has a significant impact on the technology commercialization phase with the case company having a desire to develop technologically superior products. The prioritized success factors were the freedom to operate and being able to use patents for establishing and gaining new collaborative R&D project contracts. This thus motivates assigning a relatively high weight to technological factors as these aspects aim to capture the technological relevance of the patents.

5.1.5.3. Market factors

The market aspect was given a score of 20% and captures the market size, licensing and technology potential considerations. For market size and licensing, it was attributed a score of 5%, which is based on internal interviews (Customer strategy director and R&D manager interviews, 2024). Rather than considering new entrants, the interviews conducted led to an ecosystem analysis (Customer strategy director and R&D manager interviews, 2024) determining that patent value potentially is dependent on the existing capabilities of the patent owner to exploit the market potential.

Consequently, the value chain positioning metric was given a score of 10% since it captures the ecosystem dimension by analyzing overlapping capabilities within the aerospace value chain.

5.1.5.4. Strategy factors

The strategy aspect was given a score of 25% due to the purpose of the patent portfolio analysis being the assessment of the firm in comparison to the market context. The sector trend metric was given the highest score within the strategy category of 15% since it compares the technological field of the patent with the patenting fields of the market, which should be an important consideration in benchmarking.

Patent investment in turn reflects the recent internal importance of certain technological fields for the company in terms of patenting, continuing to invest in those fields may thus be important to stay competitive, and it was consequently given a score of 10%. In attaining the success factor of using patents for collaborative R&D it could be important to keep investing in the technological areas that have been of strong importance for the company to keep the contracts. This is also aligned with the patenting considerations of the case company, where those areas were emphasized as especially important for the patenting decision (Customer strategy director; 4/4 2024).

5.1.6. Final score

The final score is obtained by the sum of each metric and multiplied by the corresponding weight of each category, as described in the previous section. To have a result between 0 and 1 and have a relative value for each metric, each metric was normalized using the min-max method, as described in more detail in the "Data analysis and treatment" section.

$$\text{Patent score} = w_1 * L + w_2 * O + w_3 * C + w_4 * FC + w_5 * BC + w_6 * ST + w_7 * MS + w_8 * Li + w_9 * V + w_{10} * S + w_{11} * PI$$

Where w = the defined weight, L= Litigation, O = Opposition, C = Claims, FC = Forward Citations, BC = Backward Citations, ST = Substitute Technology, MS = Market Size, Li = Licensing, S = Sector Trend, V = Value Chain Positioning and PI = Patent Investment

An overview of the index metrics components, how they are measured, at what level of analysis the measurement is done, the weight assigned to each metric and the data that needs to be collected can be found in Appendix A at the end of the report.

5.5. Benchmarking results

In this chapter, the benchmarking results based on the previously defined patent valuation index will be presented. Firstly, the overall results for the industry will be presented, then for the tiers, and lastly within the tier of the case company, the first-tier suppliers.

5.5.1. Industry benchmarking

On an industry level, it can be seen that in general, the larger companies also expectedly patent more within AM. General Electric and RTX by far have the largest number of patents within additive manufacturing. Patenting activity on the other hand is almost non-existent for component suppliers and some of the casting and forging houses (see Figure 3). An important point to make is that The Carlyle Group, Sequa, Barnes, and Aubert & Duval have one patent family each that their average scores are based on. The downstream parts of the value chain in terms of component suppliers and casting/forging houses therefore do not seem to have an extensive patenting strategy with regards to AM.

When analyzing the patent portfolio quality average, it can be noted that Kawasaki has the highest patent score, followed by Melrose and Hanwha. However, all these companies have rather small patent portfolios relative to the other tiers downstream in the value chain that their average patent scores are based on. However, relative to each other there are differences with regard to the size of the patent portfolios. Hanwha has 16 patents, whereas MTU has 9 and Melrose has 7. Patenting activity within AM does however not seem to be higher the closer the end-customer the actors get, as RTX and General Electric[8] are system providers and have considerably more patents within AM than Boeing and Airbus.

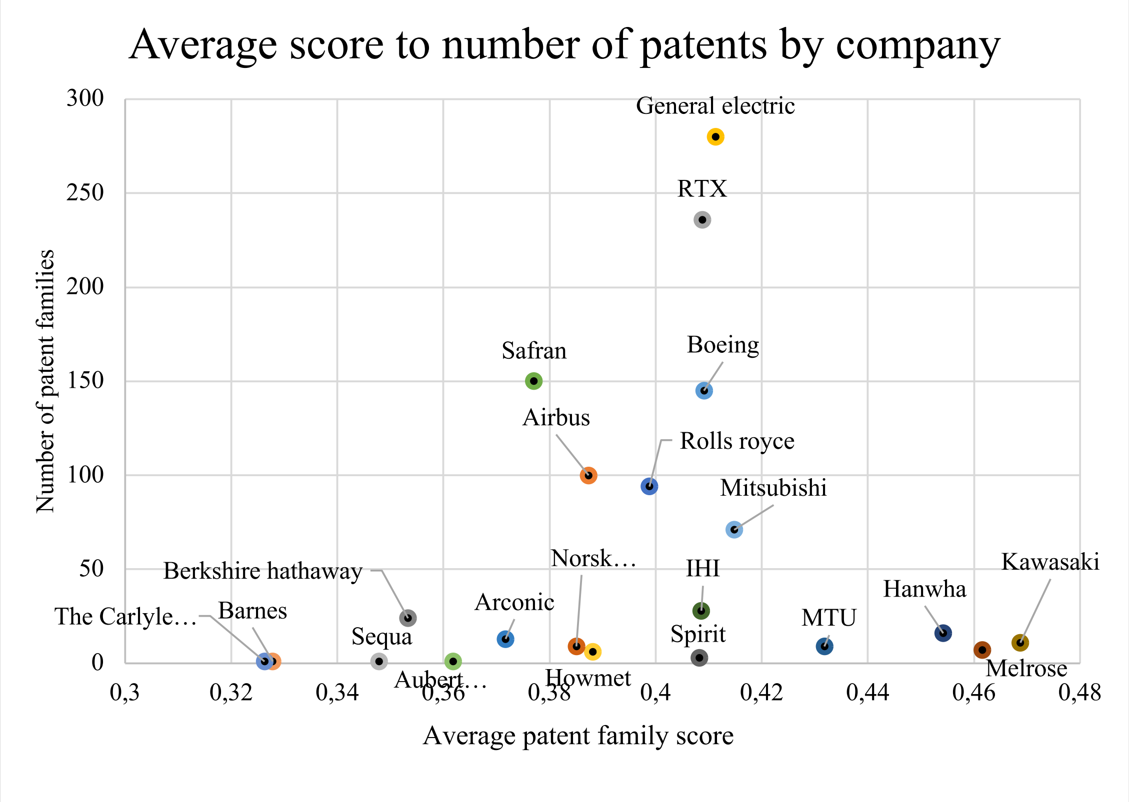

Figure 3. Average score of each company’s AM patent portfolio in relation to the number of patent families within the AM patent portfolio.

5.5.2. Tier-level benchmarking

Analyzing the patent score average at a tier level showcases that the first-tier suppliers have relatively the strongest patents. System providers and aircraft OEMs also have quite strong patents, whereas component suppliers and casting and forging houses have relatively weaker patents (see Figure 4 below).

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[8] A more detailed discussion around General Electric patent portfolio size is given in the discussion chapter

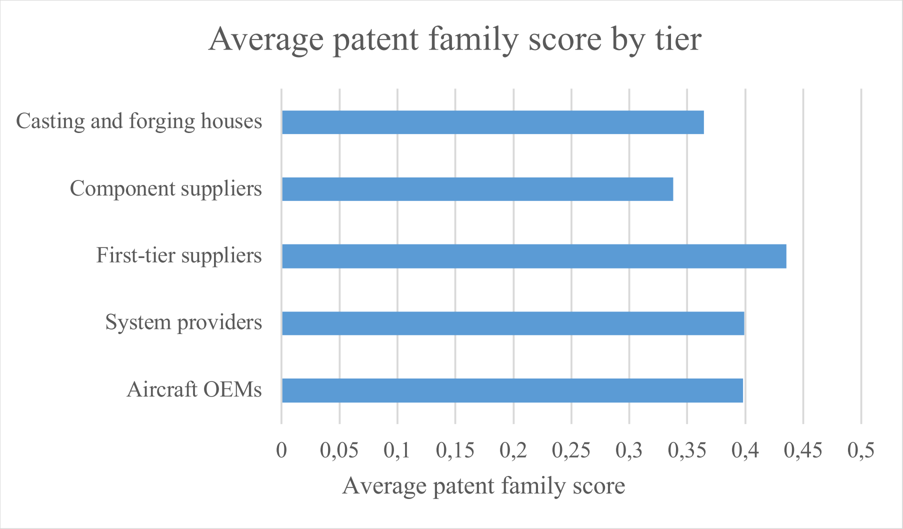

Figure 4. Average patent family score by tier.

In addition, the portfolio size of each tier highlights the dominance of system providers' investment (as signaled by patents) in AM technology and the low patenting activity of component suppliers and casting houses. It is also important to mention that two additional actors from the component and two other actors from the casting and forging houses tier were initially included in the benchmarking but did not have any patent families at all. Generally, it was found that patenting activity regardless of technological field was less common in the component supplier and casting and forging house tier, which is also the case with the AM patenting activity as can be seen in Figure 5 below.

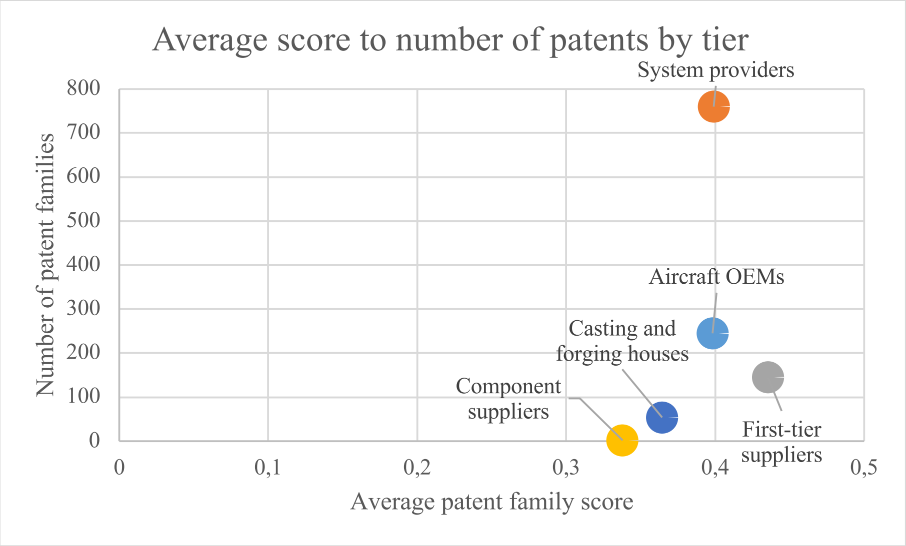

Figure 5. Average score to portfolio size by tier.

5.5.3. First-tier supplier benchmarking

In this chapter, the results of the benchmarking will be studied in more detail for the first-tier suppliers, since it may be the most important to have strong patents compared to the direct competitors. As outlined previously, these actors possess the most similar capabilities.

In terms of portfolio size, Mitsubishi has by far the largest portfolio (see Figure 6) which can be explained by the diverse activity that the company has compared to the other companies. However, their average score ranks as one of the relatively weaker. This can, in turn, be attributed to the lower family size score, and having one of the lower scores of forward citations (see Figure 7). It can also be noted that Hanwha, Melrose and Mitsubishi files patents connected to AM within technological fields that have been filed much within in general in the sector, which contributes positively to their overall patent scores. A major contributor to Kawasakis' patent score is the patent investment score, which indicates that Kawasaki has a concentrated portfolio around certain inventions within the same technological field. A detailed view of the individual metrics' contribution to the overall score is provided in Figure 7 below.

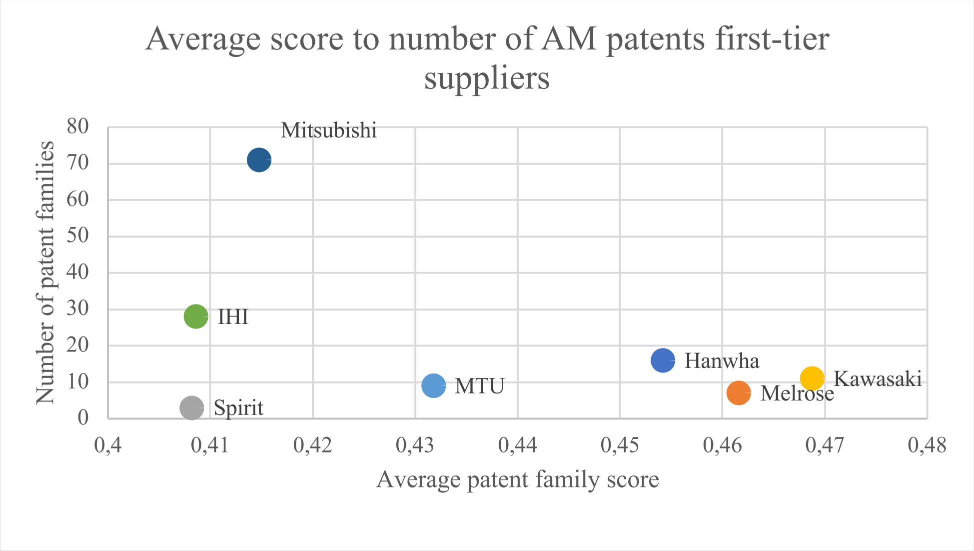

Figure 6. Score to number of AM patents within the first-tier suppliers.

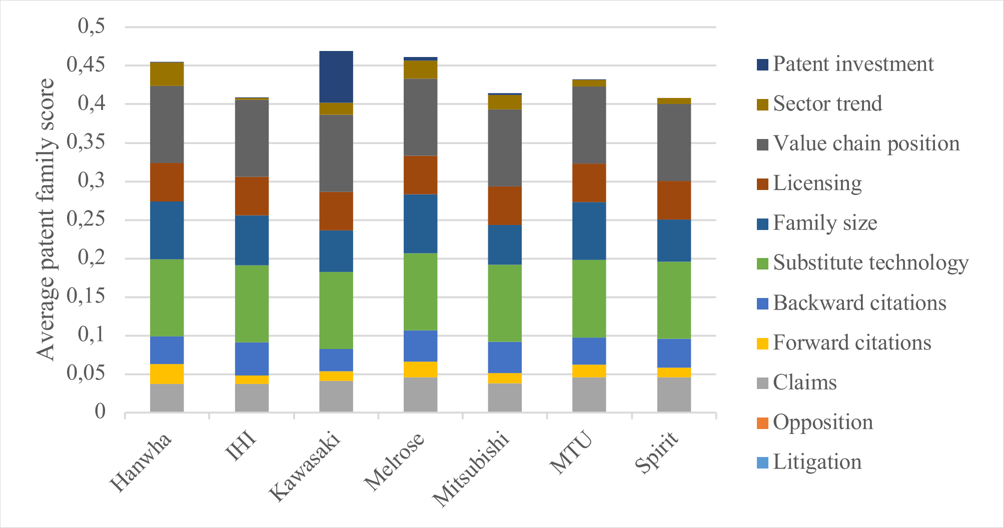

Figure 7. Average patent score by companies within first-tier suppliers.

5.5.4. Sensitivity analysis

The variation of factors in the index, such as selecting fewer metrics or changing the metrics weight setting will highly impact the patent portfolio scores which is the desired output when developing an index which takes in consideration the contextual factors of patent valuation. This chapter will analyze the value chain positioning metric for sensitivity analysis in order to study its impact on the overall result. Not including the metric in the valuation means assuming all the actors have the same capabilities.

Therefore, an analysis of the capability assumption highlights how it impacts the patent value, and uncertain assumptions around certain actors' capabilities in the development of additive manufacturing may help decision makers notice actors with high patent values disregarding the metric. Figure 8 depicts the average patent family score of each company without the value chain positioning score, while Figure 9 includes the value chain positioning score.

Regarding the average score from the patents, Kawasaki has the highest average score for their patent portfolio with the value chain positioning score included, followed by Melrose and Hanwha (see Figure 9), which are all part of the first-tier of suppliers. Since the value chain positioning score increases the value of the first-tier supplier's patents relative to the other tiers, it explains the fact that these actors' patents are consistently valued higher. If the value chain positioning score is not included, Howmet, followed by Norsk Titanium and Arconic get the highest scores (compare Figure 8 and Figure 9). Therefore, it can be noted that the value chain positioning score affects the score to a great extent, which is also expected and desired due to the assumptions, but important to emphasize. It is also interesting from an ecosystem perspective since it depicts that actors within the casting and forging house tier which Norsk Titanium and Arconic are part of have strong patents. Only considering the tier of the case company of this study without having an ecosystem perspective could have led to missing out on those portfolios.

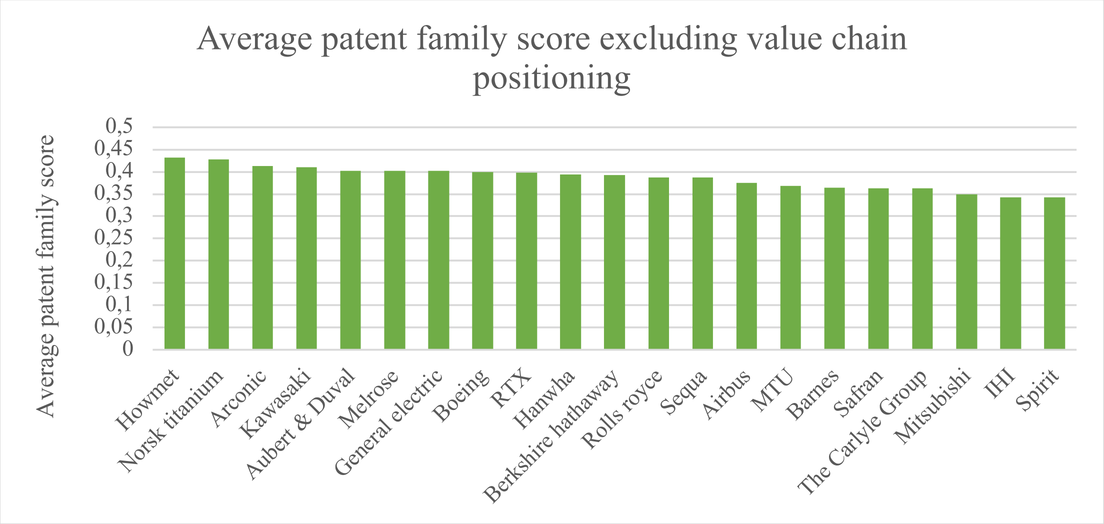

Figure 8. Chart summarizing the average patent value of the companies excluding the value chain positioning metric.

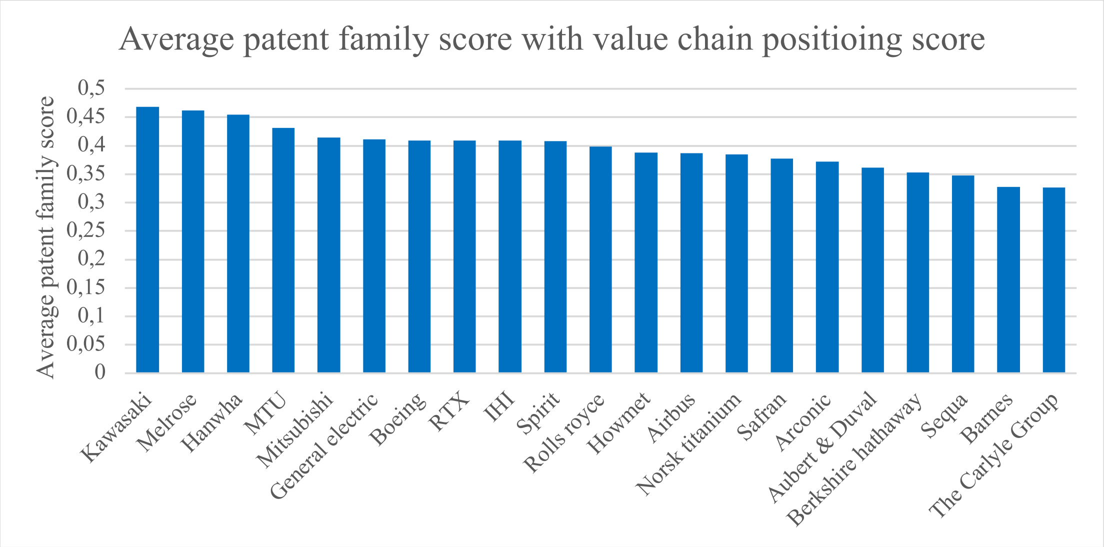

Figure 9. Chart summarizing the average patent family value of the companies including all metrics, i.e. also including the value chain positioning metric.

5.5.5. Key areas of patenting in additive manufacturing

The patents within AM have 99 different main CPC codes, but two of them dominate the share of patents and capture 40% of the patents' main CPCs. B23K captures 22%

of the patents and B29C captures 18%. The result of this analysis is summarized in Table 9 below which identifies the main areas for patenting within AM.

B23K and B29C are both patent classes targeting the process and methods. B32B, instead, focuses on layered products comprising different kinds of material. F05D relates to machinery production methods and is dedicated to heat-exchange apparatuses or systems in general. It includes various types of heat-exchange apparatuses like condensers, evaporators, or radiators. C22C contains alloys and its applications which then can have application in CPC class B22F, a class only dedicated to working metallic powder for in manufacturing process and apparatus. Finally, the subclass B33Y covers additive manufacturing, irrespective of the process or material used. This subclass is intended to enable a comprehensive search of subject matter related to additive manufacturing by combining classification symbols of this subclass with classification symbols from other subclasses. Therefore, this subclass covers aspects of additive manufacturing that might also be entirely or partially covered in other CPCs. Overall, it is seen that both product and process patents are filed in the AM field, with a heavier weight on processes.

CPC code	Most common subclasses	Share of patents' main CPC	Definition	Main field of innovation
B23K	1/*[9], 10/*, 11/*, 20/*, 26/*, 9/*, 35/*	22%	Soldering/unsoldering; welding; cutting by applying heat locally, e.g. flame cutting; working by laser beam	Process[10]
B29C	33/*, 64/*, 70/*, 73/*	18%	Shaping or joining of plastics; shaping of material in a plastic state, not otherwise provided for; after-treatment of the shaped products, e.g. repairing	Process
B32B	15/*, 5/*, 3/*	6%	Layered products, i.e. products built up of strata of flat or non-flat, e.g. cellular or honeycomb	Product
F05D	2230/*, 2250/*, 2300/*	6%	Indexing scheme for aspects relating to non-positive-displacement machines or engines,	Process (2230*/ and 2300/*) and product (2250/*)

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[9] * Denotes a wildcard figure, meaning it can be followed by any additional set of numbers

[10] Subclass B23K 101/* includes products, but no patents within that subclass, similar analysis has been made to determine if process or products is the main field of innovation for the CPC class

			gas-turbines or jet-propulsion plants	
C22C	1/*, 19/*, 47/*	5%	Metallurgy; Alloys, their composition and alterations to composition, making alloys by powder metallurgy	Process
B22F	10/*, 220*/*, 3/*	5%	Working metallic powder; manufacture of articles from metallic powder; making metallic powder; apparatus or devices specially adapted for metallic powder	Process
B33Y	N/A[11]	5%	Additive manufacturing, i.e. manufacturing of three-dimensional 3-d objects by additive deposition, additive agglomeration or additive layering, e.g. by 3-d printing, stereolithography or selective laser sintering	N/A

Table 9. Summary of which technological fields within AM are being patented the most by the aerospace actors.[12]

6. Discussion

This section will provide a discussion focusing on the development of the index, how the benchmarking results can be understood and how the framework can be used for management in the benchmarking process.

6.1. Creation of the index

The valuation index developed provides a new approach for benchmarking. The approach enables the decision-maker to dynamically analyze and rebalance the individual parts of the patent score, which differs from the aggregate scores offered by benchmarking software. Additionally, it aligns the strategic objectives of the focal

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[11] N/A since no subclass of CPC is more common than the other within B33Y based on the patent search, consequently it cannot be said if process or product innovation is patented more within this CPC since the class includes both

[12] Sources: Data from own patent search and definitions based on WIPO CPC classifications.

firms' patenting strategy with the benchmarking process, which has been emphasized as an important consideration for IP competitive intelligence (Pargaonkar, 2016). Yet, this has not been done for benchmarking purposes in previous valuation models.

The incorporation of important strategic considerations was partly made possible through the selection of metrics. When selecting the metrics to be incorporated in the index, a main consideration was to provide a holistic valuation method capturing the different aspects of the portfolio value and for that reason, metrics covering legal, technology, market and strategic aspects were incorporated. This thesis has highlighted an approach to doing it but also showcases the difficulties that follow. The previous indexes in the body of patent valuation literature have ranged from 2 to 44 metrics (Ernst and Omland 2011; Cricelli et. al, 2021). This approach of incorporating 11 metrics and assigning weights to them made the interpretation of the results from each impact category complex to grasp. It can be argued that for this valuation purpose it is necessary to find a balance between holistic and manageable valuation indexes. However, it is important to emphasize that the proposed valuation framework sheds light on the more general difficulties of patent valuation. The input in the proposed valuation index is arguably information that managers have or that would otherwise be valuable to reflect upon for a well-functioning patenting strategy. Therefore, even if the proposed framework is more resource demanding than other frameworks it contributes to clearly outlining assumptions regarding what constitutes patent value for the specific valuation purpose considering firm, industry and technology aspects.

The outcome of the literature review and the insights from the interviews led to the inclusion of a metric that has previously only been considered qualitatively in the IP literature in terms of the capabilities of different actors (Teece et. al, 1997; Holgersson et. al, 2022), the value chain positioning metric. The concept of complementarities described by Holgersson et. al (2022) highlights that activities may be complementary which makes it beneficial to collect those activities in the same business unit as opposed to offering it in separate units on the market. Related to this case within additive manufacturing, it was highlighted that manufacturing and design capabilities could be one such factor, which would strengthen the relative patent strength of first-tier suppliers compared to for example forging and casting houses in the development of AM. The sensitivity analysis (see section 5.5.4. Sensitivity analysis) showed that the inclusion of the metric and the set weight changed the positioning to a large degree, and a quite generalized approach was taken where the tier level was the level for discrimination among actors. However, managers who have a good understanding of their businesses could choose to use the metric for discriminating among actors within the same tier if their capabilities differ, which may be even more useful. An alternative to the metric could be to directly do a narrower inclusion of actors for the benchmarking and not include those that are not considered to have capabilities strong enough to challenge the benchmarking company's market position. However, when new technology emerges it may be uncertain to what extent actors in other parts of the value chain, or even within entirely different businesses, could challenge the market position

(Carlgren et. al, 2016). In cases similar to this study, it could thus be argued that rather viewing capabilities as barriers to vertical integration may be more useful and that assumptions regarding overlapping capabilities may provide useful insights into the strategic positioning and possible shifts in the competitive landscape, which is one of the major reasons for performing benchmarking (Breitzman and Mogee, 2002). It might be important to underline that it is hard to know the capabilities of other companies, but educated guesses and sensitivity analyses may provide interesting insights into possible scenarios, and the inclusion of the metric can aid in noticing certain portfolios that would otherwise go unnoticed.

Furthermore, the weight setting was a critical aspect that directly impacted the patent score which is dependent on subjective considerations, such as the managers' input on the business priorities. As Cricelli et. al, (2021) argued, the weight setting is a complex and sensitive process requiring experts to perform this task. This thesis has demonstrated how weight setting can be performed by gathering information from technology experts and managers. An experienced manager together with technological experts within the benchmarked technology are arguably the most suitable people to conduct this kind of benchmarking and setting weights. The accuracy of the model would arguably be higher if these experts performed the weighting process. Furthermore, AHP or Delphi methods could be more structured approaches to set the weights (Zhang et. al, 2017) than the approach of interviewing managers which was used in this thesis. In the scope of this master thesis, it was however not possible to have continuous communication at the case company to iteratively set weights together with managers, or conduct a Delphi-based weight setting. In organizations implementing this or similar frameworks, that would however be a recommended approach to prioritization of metrics.

6.2. Contrasting the results of the benchmarking

The findings on AM showcase differences regarding the positioning of the actors in the technology development. Concerning the company patent portfolio sizes, it is important to point out that General Electric operates within many fields apart from aerospace, so some patents captured may not be developed with intentional usage within aerospace. The querying instead more generally captures AM patents and applications for AM concerning metals or alloys. It could however be argued that those patents could also be valuable for aerospace applications depending on the company's capabilities connected to the internal transfer of knowledge, and that is the reason why further restrictions regarding only aerospace subsidiaries were not made. However, it might be advisable to interpret the number of patents within AM for aerospace applications with caution regarding General Electric.

The high investment in AM observed through the dominance in size and quality of patent portfolios in AM from the system providers and first-tier suppliers suggests a focus on supplying sustainable and cost-efficient products, which may constitute an important competitive advantage for the actors at the forefront of that development. Casting and forging houses do not seem to invest as heavily in AM, based on the benchmarking as other actors, despite the technique being related to the building of material in a more sustainable and cost-effective way. At the same time, many of the casting and forging houses are relatively small actors with small overall patenting activity. Norsk Titanium and Arconic do not have many patents, but they have strong patents when disregarding the capability assumption. The capability assumption for these actors could thus be interesting to analyze since if they would be considered to have overlapping capabilities to a larger degree their patent scores would also increase.

Furthermore, patenting as an investment indicator, especially for process technology such as AM might not give the full picture, since manufacturing processes can be protected through other means of protection such as secrecy (Teece, 1986; Bechtold, 2016). Therefore, it is still possible that the investment of casting and forging houses invest in AM but keep it secret to a larger degree.

Connected to the balance between secrecy and patents, this thesis has also generated clues relating to the role of patents in protecting different elements of AM. The literature suggests that products are more suitable for patenting than processes (Teece, 1986; Holgersson & Wallin, 2017). AM is a process technology, but at the same time, it is possible to also protect the end products of AM by targeting the layering and composition of the products. The analysis on which main CPC codes were used for patenting (see section 5.5.5. Key areas of patenting in additive manufacturing) suggested this is done to some degree, but still the vast majority of patents target processes. Probably for every patent on AM, there are several trade secrets due to it being a process technology, but this thesis could only speculate on to which degree that is the case or not, however, the general literature would suggest so (e.g. Bechtold, 2016). One possible reason to patent a process in AM despite the possibility of protecting it as a trade secret could be to facilitate collaboration and knowledge-sharing. That would be aligned with the general notion that intellectual property rights are essential tools for supporting knowledge-sharing and collaboration between actors (Arrow, 1962; Holgersson et. al, 2022; Manzini & Lanzarotti, 2015), and as described throughout the thesis, collaboration is also a prominent feature within the aerospace industry, which may be aided using intellectual property rights. That could also explain why actors downstream in the value chain have a higher patenting activity than those upstream in the value chain, since the downstream actors collaborate to a larger degree, and are required to share their knowledge through those collaborations to a larger extent.

6.3. Data collection

As mentioned in the method, the query creation required first an understanding of the AM technology and then about the used software. The involvement of the IP and AM engineers was critical for the query results which in turn impacted the patent valuation results. Being able to deduce which CPCs and search terms most effectively capture a specific technology was important for capturing relevant patents. The more technological knowledge the valuation team has the more accurate results will most likely be obtained. At the same time, to be able to capture the AM portfolios of the involved actors the query terms were broad including multiple CPC codes, key AM terms, and metal or alloy applications. The CPC codes included a large range of patents and within the same CPC code, there may be subclasses that are tangent to additive manufacturing without purely being additive manufacturing. An example of this is welding, which should only be considered additive manufacturing if it is done repeatedly in terms of layering (AM engineer, 3/4/2024). By reviewing the captured patents with an IP engineer as mentioned in the method, an approach was adopted where a balance between patent accuracy and portfolio representativeness was sought.

A critical aspect of the patent search was the CPC code selection. CPC codes provide a technological segmentation for research, however, the taxonomy of the CPC classes might in some cases not provide as detailed information, as it would have been desirable for this thesis. An example of this is the B33Y code which is described as AM generally. In this case, there is no distinction between products or processes, instead, the CPC contains both and can additionally overlap with other CPC codes. Furthermore, even when going into great detail in terms of subclass definition within a CPC code, such as specifying B23K 26/062, that category still includes working by either electron beam or laser beam, which makes an analysis regarding which elements of the technology the actors prioritize to patent hard, especially when classifying large amounts of patent data such as in this thesis. A more overarching level of patent classification in terms of product or process would have been beneficial for benchmarking purposes, but also for inventors becoming more aware of the existing patent inventions.

The usage of Cipher and Patseer has enabled the collection of patent data which has been beneficial for this study. These software also incorporate AI tools to support the patent search and find new patents. This tool can be useful, however, the lack of transparency on the methods used could be a barrier to using such approaches, especially for academic settings, and was a reason why such an approach was not used in this thesis. Instead, a more traditional approach to manually defining CPC codes and search terms was performed.

6.4. Management implications

The index developed is a benchmarking method that can be seen as a support tool for IP engineers in collaboration with managers taking strategic decisions based on the patent value insights which aligns with the desired implementation suggested by e.g.

Pargaonkar (2016). The framework development was done in combination with the use of appropriate software for patent search, analysis, and repository and guided by an IP team which is in line with what Pargaonkar (2016) proposes for turning patent information into intelligence. The tool in turn can support portfolio management, technology investment, market positioning, and more broadly the IP strategy definition. In this thesis, the method has been demonstrated for comparison of patents within the same technology. However, it has been developed to be used to compare different technologies. The licensing and substitute technology metrics are classified at a technology level and when comparing the same technology, they do not impact any relative values for the benchmarking process. They do however contribute to valuable insights when managers need to prioritize investment in one technology over another.

The weight setting process could be an obstacle to the usability of the framework especially when using it for comparing several different technologies since the framework contains 11 metrics, and different weights would be set differently for different technologies, making it a time-consuming process. It could however be argued that the weight setting process is an important part of outlining the assumptions around what constitutes value for the particular technology and quantifying those assumptions, based on the understanding of the technologies, firm objectives, and industry structure, which could constitute value on its own as a point of discussion. A sensitive aspect of the framework was the selection of success factors and the weight setting, yet they are considered a central step for the development of a robust valuation index. Pargaonkar (2016) suggests an advancement compared to the process suggested in this thesis, where the process ideally should be supported by the entire IP valuation community which can include various professionals such as patent attorneys, technologists, finance, marketing, and strategy executives. However, the inclusion of different entities and experts from different backgrounds would make it even more resource demanding.

Portfolio management involves evaluating the composition and performance of the patent portfolio using insights gained from the index which Grimaldi et. al, (2015) suggests that is important for portfolio strategic guidance. In this case, with the benchmarking insights, the managers at the case firm can assess the strengths and weakness of the portfolio compared with other first-tier actors, but also in comparison with the other industry tiers. Secondly, the identification of the CPC codes that are patented the most within AM provides a more detailed overview of the competitors' R&D investments through patents and also the company's alignment with the industry trends. In a consequence of this analysis, there is a possibility for strategic positioning and R&D investment in areas where the company is lagging behind. Additionally, opportunities for collaboration and licensing could be assessed through the evaluation of actors' patent portfolios. The development of the index is recommended to be integrated in the IP strategy of the firm which in turn can be guided by senior IP managers and connected to the overall strategy (Pargaonkar, 2016) as in this study is expected to be achieved by the selection of the success factors.

7. Conclusion

Patent valuation for strategic purposes is a highly contextual process. What constitutes value for a patent depends on the industry, firm and underlying technology. This thesis has outlined a valuation process considering many of the contextual factors by selecting metrics and a weight setting process for these metrics, incorporating success factors into the valuation context. The case study of additive manufacturing within the aerospace industry has acted as an example of how industry, firm and technology factors can be taken into consideration. The sensitivity analysis has made it evident that assumptions around the success factors highly affect the obtained result. It is also important to find a balance between being able to capture success factors holistically while still being manageable for the decision-maker. While this study has proposed a valuation framework that requires a lot of assumptions to be made this does not have to be seen as something negative since decision-making to a high degree concerns handling uncertainty and outlining such assumptions could rather be beneficial for a comprehensive IP strategy. Furthermore, it can be used to dynamically understand and analyze how the parameters affect the patent value and act as a discussion for what constitutes the value of patenting. This differs from many of the current valuation techniques which do not incorporate success factors, and which give one definitive value to the decision-maker without highlighting that patent value is highly contextual.

In assessing the patenting activity within the aerospace industry for additive manufacturing, this study further suggests that system providers and aircraft OEMs have large patent portfolios on the technology, first-tier suppliers have smaller but in terms of quality seem to have equally or more valuable portfolios. However, it is important to emphasize that this does not equate to certain actors having low R&D investment in additive manufacturing technology since patenting is only one of several means of protection. Furthermore, the vast number of patents are filed within methods, and a much smaller amount concerning the composition of AM products. A possible explanation for why actors choose to patent methods, despite the possibility of protecting it through trade secrets could be to facilitate collaborative R&D, which is a prominent feature within the industry.

8. Further research

The framework outlined in this thesis has been developed based on the insights from the developments of an emerging technology in the aerospace industry. For further research, it would be interesting to research also how the framework can be readapted in other settings and for comparing different technologies in an entire portfolio. In this thesis, it has only been applied to additive manufacturing.

In constructing useful patent valuation indexes further research would also be needed on how the individual metrics components interplay when combining them and their overlap in explanatory power. As discovered in this thesis a reduction of the components would be useful for increasing the usability of patent valuation indexes while being able to capture essential value drivers for the valuation context.

Future research could also focus on investigating the empirical validity of different metrics in different industries and technologies. The few available studies show that there are industry differences in the explanatory power of certain metrics (e.g. Harhoff et. al, 2003; Beschorner, 2008; Denicolo, 1996), so therefore conducting further research and systematizing the findings would aid further in the implementation of a valuation index for patents in specific industry contexts such as the one analyzed in this thesis.

References

Arora, A. (1997). Patents, licensing, and market structure in the chemical industry. Research Policy, 26(4-5), pp.391–403. doi: https://doi.org/10.1016/s0048-7333(97)00014-0 .

Arrow, Kenneth J. Economic Welfare and the Allocation of Resources for Invention, in The Rate and Direction of Inventive Activity, 609 (Nat'l Bureau of Econ. Research ed. 1962).

Azzam, J.E., Ayerbe, C. and Dang, R. (2017). Using patents to orchestrate ecosystem stability: the case of a French aerospace company. International Journal of Technology Management, 75(1/2/3/4), p.97. doi: https://doi.org/10.1504/ijtm.2017.085695.

Bechtold, S. (2016). 3D Printing, Intellectual Property and Innovation Policy. IIC - International Review of Intellectual Property and Competition Law, 47(5), 517–536. https://doi.org/10.1007/s40319-016-0487

Bell, E., Bryman, A., & Harley, B. (2022). Business research methods. Oxford university press.

Beschorner, P. F. E. (2008). Optimal patent length and height. Empirica, 35(3), 233–240. https://doi.org/10.1007/s10663-007-9059-7

Breitzman, A. F., & Mogee, M. E. (2002). The many applications of patent analysis. Journal of Information Science, 28(3), 187–205. https://doi.org/10.1177/016555150202800302

Bruno and Malwina Mejer (2009). The London Agreement and the cost of patenting in Europe. European Journal of Law and Economics, 29(2), pp.211–237. doi: https://doi.org/10.1007/s10657-009-9118-6 .

Carlgren, L., Elmquist, M., & Rauth, I. (2016). The Challenges of Using Design Thinking in Industry – Experiences from Five Large Firms. Creativity and Innovation Management, 25(3), 344–362 https://doi.org/10.1111/caim.12176

Caviggioli, F. and Ughetto, E. (2013). The drivers of patent transactions: corporate views on the market for patents. R&D Management, 43(4), pp.318–332. doi: https://doi.org/10.1111/radm.12016 .

Cricelli, L., Grimaldi, M., Rogo, F. and Strazzullo, S. (2021). Patent ranking indicators : a framework for the evaluation of a patent portfolio. International journal of intellectual property management : IJIPM,. https://www.econbiz.de/Record/patent-ranking-indicators-a-framework-for-the-evaluation-of-a-patent-portfolio-cricelli-livio/10012511872

Demirden, S. F., Kimiz-Gebologlu, I., Alptekin, K., & Senyay-Oncel, D. (2023). Importance of Intellectual Property Rights for Building a Sustainable Future. A Sustainable Green Future, 69–94. https://doi.org/10.1007/978-3-031-24942-6_4

Denicolofor, V. (1996). Patent Races and Optimal Patent Breadth and Length. The Journal of Industrial Economics, 44(3), 249. https://doi.org/10.2307/2950496

Ernst, H., & Omland, N. (2011). The Patent Asset Index – A new approach to benchmark patent portfolios. World Patent Information, 33(1), 34–41.https://doi.org/10.1016/j.wpi.2010.08.008

Elkington, B. (2012). IP management in aerospace and defense. iam-magazine.com.

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S., & Zavattieri, P. D. (2015). The status, challenges, and future of additive manufacturing in engineering. Computer-Aided Design, 69(69), 65–89. https://doi.org/10.1016/j.cad.2015.04.001

Gibson, I., Rosen, D., Stucker, B. and Khorasani, M. (2021). Additive Manufacturing Technologies. Cham: Springer International Publishing. doi: https://doi.org/10.1007/978-3-030-56127-7 .

Girgin Kalıp, N., Erzurumlu, Y. Ö., & Gün, N. A. (2022). Qualitative and quantitative patent valuation methods: A systematic literature review. World Patent Information, 69, 102111. https://doi.org/10.1016/j.wpi.2022.102111

Granstrand, O. and Holgersson, M. (2014). Multinational technology and intellectual property management - is there global convergence and/or specialisation? International Journal of Technology Management, 64(2/3/4), p.117. doi: https://doi.org/10.1504/ijtm.2014.059931 .

Grimaldi, M., Cricelli, L., & Rogo, F. (2018). Valuating and analyzing the patent portfolio: the patent portfolio value index. European Journal of Innovation Management, 21(2), 174–205. https://doi.org/10.1108/ejim-02-2017-0009

Grimaldi, M., Cricelli, L., Di Giovanni, M., & Rogo, F. (2015). The patent portfolio value analysis: A new framework to leverage patent information for strategic technology planning. Technological Forecasting and Social Change, 94, 286–302. https://doi.org/10.1016/j.techfore.2014.10.013

Hall, B. H., Jaffe, A., & Trajtenberg, M. (2005). Market Value and Patent Citations. The RAND Journal of Economics, 36(1), 16–38. http://www.jstor.org/stable/1593752
Hall, B.H. and Harhoff, D. (2012). Recent Research on the Economics of Patents. Annual Review of Economics, 4(1), pp.541–565.

Harhoff, D., Scherer, F. M., & Vopel, K. (2003). Citations, family size, opposition and the value of patent rights. Research Policy, 32(8), 1343–1363. https://doi.org/10.1016/s0048-7333(02)00124-5

Holgersson, M., & Wallin, M. W. (2017). The patent management trichotomy: patenting, publishing, and secrecy. Management Decision, 55(6), 1087–1099. https://doi.org/10.1108/md-03-2016-0172

Holgersson, M., Baldwin, C. Y., Chesbrough, H., & M. Bogers, M. L. A. (2022). The Forces of Ecosystem Evolution. California Management Review, 64(3), 5–23. https://doi.org/10.1177/00081256221086038

Hu, X., Rousseau, R., & Chen, J. (2011). On the definition of forward and backward citation generations. Journal of Informetrics, 5(1), 27–36. https://doi.org/10.1016/j.joi.2010.07.004

Independent and dependent claims. (n.d.). Www.epo.org. Retrieved April 20, 2024, from https://www.epo.org/en/legal/guidelines-epc/2022/f_iv_3_4.html

Karayel, E., & Bozkurt, Y. (2020). Additive manufacturing method and different welding applications. Journal of Materials Research and Technology, 9(5), 11424–11438. https://doi.org/10.1016/j.jmrt.2020.08.039

Katz, M.L. and Shapiro, C. (1985). Network Externalities, Competition, and Compatibility. The American Economic Review, [online] 75(3), pp.424–440. Available at: https://www.jstor.org/stable/1814809.

Kocarev, L., Galias, Z. and Lian, S. (2009). Intelligent Computing Based on Chaos. [online] Google Books. Springer. Available at: https://books.google.se/books?hl=pt-PT&lr=&id=N91rCQAAQBAJ&oi=fnd&pg=PR1&dq=Galias [Accessed 9 May 2024].

Lagrost, C., Martin, D., Dubois, C., & Quazzotti, S. (2010). Intellectual property valuation: how to approach the selection of an appropriate valuation method. Journal of Intellectual Capital, 11(4), 481–503. https://doi.org/10.1108/14691931011085641

Lanjouw, J. O., & Schankerman, M. (2001). Characteristics of Patent Litigation: A Window on Competition. The RAND Journal of Economics, 32(1), 129. https://doi.org/10.2307/2696401

Lanjouw, J. O., & Schankerman, M. (2004). Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. The Economic Journal, 114(495), 441–465. https://doi.org/10.1111/j.1468-0297.2004.00216.

Manzini, R., & Lazzarotti, V. (2015). Intellectual property protection mechanisms in collaborative new product development. R&D Management, 46(S2), 579–595. https://doi.org/10.1111/radm.12126

Mocenco, D. (2015). Supply chain features of the aerospace industry particular case airbus and boeing. Scientific Bulletin-Economic Sciences, 14(2), 17-25.

Najmon, J.C., Oliveira, J.P., Santos, T.G. and Miranda, R.M. (2020). Revisiting fundamental welding concepts to improve additive manufacturing: From theory to practice. Progress in Materials Science, 107, p.100590. doi: https://doi.org/10.1016/j.pmatsci.2019.100590 .

Orsenigo, Luigi & Sterzi, Valerio. (2010). Comparative Study of the Use of Patents in Different Industries. Knowledge, Internationalization and Technology Studies (KITeS). 33/2010.

Osorio, A., Naranjo-Valencia, J. C., Calderon-Hern, G., & ez. (2019). The Operationalization of Competitive Strategy: Choosing an Appropriate Method of Measurement. Academy of Strategic Management Journal, 18(4), 1–394. https://www.abacademies.org/articles/the-operationalization-of-competitive-strategy-choosing-an-appropriate-method-of-measurement-8396.html

Pargaonkar, Y. R. (2016). Leveraging patent landscape analysis and IP competitive intelligence for competitive advantage. World Patent Information, 45, 10–20. https://doi.org/10.1016/j.wpi.2016.03.004

Peters, T., Thiel, J., and Tucci, C.L. (2013), 'Protecting growth options in dynamic markets: The role of strategic disclosure in integrated intellectual property strategies'. California Management Review, Vol. 55, No. 4, pp. 121-142. (Available here: https://journals.sagepub.com/doi/abs/10.1525/cmr.2013.55.4.121)

Porter, M.E. (1989). How Competitive Forces Shape Strategy. Readings in Strategic Management, [online] 57(2), pp.133–143. doi: https://doi.org/10.1007/978-1-349-20317-8_10

Pose-Rodriguez, Javier & Ceulemans, Judy & Ménière, Yann & Nichogiannopoulou, Aliki & Rudyk, Ilja. (2020). Patents and additive manufacturing: Trends in 3D printing technologies.

Prock, T., Roberts, P., Sizer, D., & Jefferies, M. (2020, June 20). Is 3D printing a threat to the value of IP portfolios? Www.iam-Media.com. https://www.iam-media.com/article/3d-printing-threat-the-value-of-ip-portfolios

Radhika C, Shanmugam, R., Monsuru Ramoni, & Gnanavel BK. (2024). A Review on Additive Manufacturing for Aerospace Application. Materials Research Express. https://doi.org/10.1088/2053-1591/ad21ad

Ritala, P., Agouridas, V., Assimakopoulos, D., & Gies, O. (2013). Value creation and capture mechanisms in innovation ecosystems: a comparative case study. International Journal of Technology Management, 63(3/4), 244. https://doi.org/10.1504/ijtm.2013.056900

Romer, P. (2002), 'When should we use intellectual property rights?'. AER Papers and Proceedings, May 2002, Vol 92, No. 2, pp. 213–216.

RTX, 2024, rtx.com , consulted date: 30/04/2024 Home | RTX

Singamneni, S., LV, Y., Hewitt, A., Chalk, R., Thomas, W., & Jordison, D. (2019). Additive Manufacturing for the Aircraft Industry: A Review. Journal of Aeronautics & Aerospace Engineering, 08(01). https://doi.org/10.35248/2168-9792.19.8.215

Singhal, T.S., Jain, J.K., Kumar, M., Bhojak, V., Saxena, K.K., Buddhi, D. and Prakash, C. (2023). A comprehensive comparative review: welding and additive manufacturing. International Journal on Interactive Design and Manufacturing (IJIDeM). doi: https://doi.org/10.1007/s12008-022-01152-0 .

Smith, D.J. and Tranfield, D. (2005). Talented suppliers? Strategic change and innovation in the UK aerospace industry. R and D Management, 35(1), pp.37–49. doi: https://doi.org/10.1111/j.1467-9310.2005.00370.x .

Somaya, D. (2012), "Patent strategy and management: An integrative review and research agenda", Journal of Management, Vol. 38 (4), pp. 1084-1114.

Swycher, N., & McMahon, N. (2021, February 10). Why benchmarking is essential to patent strategy and how best to use analytics. Www.iam-Media.com. https://www.iam-media.com/article/why-benchmarking-essential-patent-strategy-and-how-best-use-analytics

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research Policy, 15(6), 285–305. https://doi.org/10.1016/0048-7333(86)90027-2

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic Capabilities and Strategic Management. Strategic Management Journal, 18(7), 509–533.

van Zeebroeck, N. (2011). The puzzle of patent value indicators. Economics of Innovation and New Technology, 20(1), 33–62. https://doi.org/10.1080/10438590903038256

Wagner, S. M., & Baur, S. (2015). Opportunities and challenges for aerospace supplier firms. https://ethz.ch/content/dam/ethz/special-interest/mtec/chair-of-logistics-mgmt-dam/documents/practitioner-articles/Wagner%20Baur%202015%20Risk%20sharing%20partnership%20(RSP)%20in%20aerospace%20-%20the%20RSP%202.0%20model.pdf

Ward, M.J., Halliday, S.T. and Foden, J. (2011). A readiness level approach to manufacturing technology development in the aerospace sector: an industrial approach. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 226(3), pp.547–552. doi: https://doi.org/10.1177/0954405411418753

World Intellectual Property Indicators 2022. (2022). https://www.wipo.int/edocs/pubdocs/en/wipo-pub-941-2022-en-world-intellectual-property-indicators-2022.pdf

Zhang, Y., Qian, Y., Huang, Y., Guo, Y., Zhang, G., & Lu, J. (2017). An entropy-based indicator system for measuring the potential of patents in technological innovation: rejecting moderation. Scientometrics, 111(3), 1925–1946. https://doi.org/10.1007/s11192-017-2337-7

Appendix A

Metric	Measurement	Level of analysis	Weight (%)	Necessary data
Legal 15%				
Litigation	*Has survived litigation=1* *Has not been litigated/did not survive=0*	Patent family	5	-Litigation status -Outcome of litigation
Opposition	*Has survived opposition=1* *Has not been opposed/did not survive opposition=0*	Patent family	5	-Opposition status -Outcome of opposition
Claim	$\log(1 + number\ of\ claims\ in\ patent)$	Patent family	5	-Number of claims per patent family
Technology 35%				
Forward citations	$\frac{log\ (1 + number\ of\ forward\ citations)}{2025 - PY}$	Patent family	15	-Number of forward citations -Publication year
Backward citations	*Log(1+BC)*	Patent family	10	-Number of backwards citations
Substitute technology	*No=1* *Yes=0*	Technology	10	-Assess to what degree the patented technology could substitute current techniques
Market 20%				
Market size	*National market (more for AM):* *US=0.4* *EP=0.4* *Others=Max: 0.2, 0.05 for each* *No national market (aerospace generally):* *US: 0.5* *EP: 0.5*	Patent family and technology	5	-The national markets the patent is granted in -Establish which markets are relatively more important
Licensing	*1=no* *0=yes*	Technology	5	-Analyze potential for licensing
Value chain positioning	*Overlapping capabilities=1 (same tier)* *Partly overlapping=0.5 (Aircraft OEMs and engine OEMs)* *Not overlapping=0 (forging/casting, component suppliers)*	Tier and Technology	10	-Assess tier capabilities in relation to the benchmarking company's capabilities
Strategy 25%				
Sector trend	*(Patents nr. In given CPC '21 to '24-Patents nr. In given CPC '18 to '20)/ Patents nr. In given CPC '18 to '20*	Industry	12,5	-The number of patents among the benchmarked actors within a certain CPC code
Patent investment	*Number of patents in patent CPC class '21 to '24/ Number of patents '21 to '24*	Firm and CPC	10	- Number of patent families in patent CPC -Total number of patent families within the company

Table 10. Summary of the metrics, measurement of the metrics, level of analysis, assigned weight and patent data required for the calculation.

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