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Development and application of patent management maturity model: a capability-based perspective

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Abstract: This paper aims to develop a comprehensive patent management maturity model (PMMM) in order to support organisations to progressively analyse, understand and improve their patent management maturity (PMM). Through a thorough analysis of existing literature and an extensive survey, we have identified core components of patent management capabilities (PMCs) and categorised them into seven dimensions, each comprising two to four key elements. The meticulous description of maturity levels of the elements provides organisations with a clear roadmap for continuous improvement of their PMM. Furthermore, two Chinese manufacturing firms were chosen as examples to demonstrate how the model may be employed and its efficiency. The model is beneficial for assessing the distribution of strengths and weaknesses in various parts of organisations' PMCs and for upgrading their PMCs through integrating, building, and reconfiguring patent-related processes, thereby increasing the organisation's capability to make intelligent decisions.

Keywords: patent management capabilities; PMCs; dynamic capability; patent management maturity; PMM; maturity model; maturity levels; China; case study.

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1 Introduction

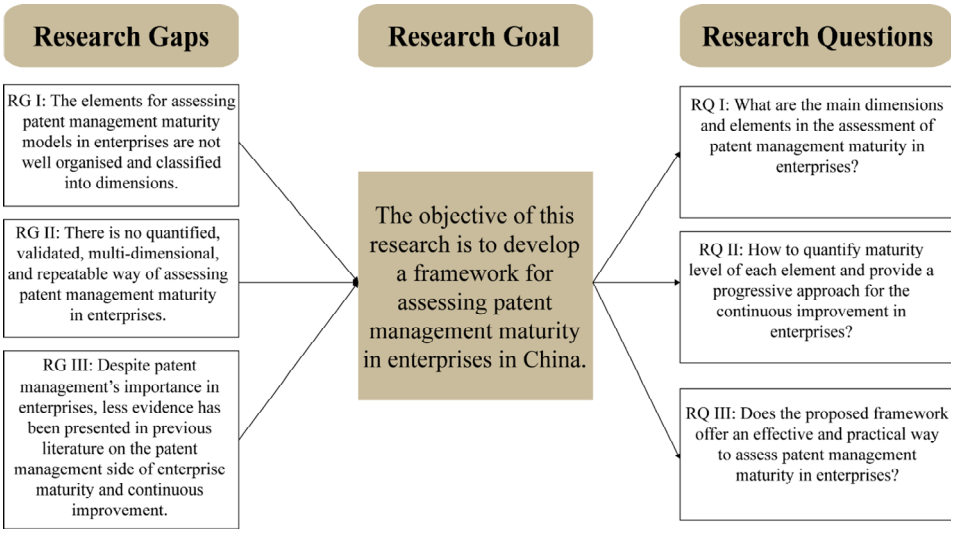
The expansion of worldwide patents in the knowledge economy and globalisation highlights the growing significance and rapid pace of technology-based competition, resulting in a fundamental shift in the relevance of patents (Fink et al., 2016; Ernst, 2017; Yang et al., 2021). Patents, as a strategic resource, not only enable the appropriation of innovation (value capture) by limiting imitation (Holgersson and Wallin, 2017), but also improve company image, motivate employees, ensure freedom to operate, and restrict rivals from specific technological sectors through retaliatory power (Holgersson, 2013; Soranzo et al., 2016). Over time, regular right assertions, market transactions, and the emergence of new patent-based business models have significantly improved managers' understanding of the importance of patents in securing and defending competitive advantage, as well as the severe consequences of neglecting patent issues (Somaya, 2012; Ernst et al., 2016; Lee et al., 2019).

Empirical research suggests that the relationship between a company's level of patent activity and its financial performance is, at best, weakly positive (Griliches et al., 1991; Ernst, 2001). Simply relying on the count of patent applications or grants as a proxy variable for a company's technological innovation performance may be inadequate or even misleading (Levitas and Chi, 2010; Ponta et al., 2021). Consequently, it is patent management (PM) rather than the sheer quantity of patents held by a corporation that ultimately determines the value derived from patents (Ernst et al., 2016; Agostini et al., 2019; Grzegorczyk and Głowiński, 2020). In fact, several studies, including Cao and Zhao (2013), Ernst et al. (2016) and Agostini et al. (2022b), have established a positive and robust association between PM and various dimensions of firm-level technological innovation performance. Moreover, case-based business observations reaffirm the importance of a company's PM skills in generating value from patents and enhancing overall performance (Reitzig and Puranam, 2009; Somaya, 2012; Soranzo et al., 2017).

PM is increasingly recognised as a strategic and managerial function integrated into overall corporate and business strategies (Fisher and Oberholzer-Gee, 2013; Soranzo et al., 2017). It is viewed as an "important enabler for securing sustainable competitive advantage" (Ernst, 2017). PM entails a complicated collection of fundamental operations via which various patent-related processes can be carried out. For instance, Jell et al. (2015) highlight the planning and evaluation of patents, while Ernst et al. (2016) identify patent protection management and patent information management as key functions. Agostini et al. (2022a) further expand these operations to operate, portfolio management, enforcement, and intelligence. However, significant challenges persist in the development of PM due to the multifaceted nature of patents and their integration into different aspects of a company, such as enterprise systems, strategy, R&D, marketing, departments, and employees (Schmidt, 2013). Despite the increasing attention given to PM research and practice, there is limited literature dedicated to illustrating and explaining how companies structure and enhance their PM holistically, primarily due to the lack of clarity in definitions and frameworks (Soranzo et al., 2016). Alternatively, while some authors distinguish between different levels of PM (Harrison and Sullivan, 2011; Kern and van Reekum, 2012), there are few examples that effectively measure the overall patent management maturity (PMM) of a firm and discuss in-depth how firms address the necessary changes to improve their PM processes (Soranzo et al., 2017). To the best of our knowledge, Teshome's (2020) PhD thesis was the first to construct and validate measurement scales for PM at the firm level. The study highlighted the need for a holistic, valid, and practical measurement instruments to monitor PM and assess firm portfolios. In fact, as noted by Moehrle et al. (2017), prior research tends to 'focus on describing patent functions' or 'ideal conceptions or specific case studies', rather than addressing the 'tasks related to PM'. This lack of guidance may hinder top management's understanding of how to effectively adopt these practices and integrate them into their own company's PM processes to enhance overall performance.

In response to these concerns, we seek to develop a comprehensive patent management maturity model (PMMM) for assessing and navigating the growth of PMM from a dynamic capability view (DCV) perspective (see Figure 1). The model aims to provide a holistic assessment of a firm's overall PMM, allowing it to grasp the current status of PM systematically. Furthermore, the model adopts a progressive and ongoing approach to outline an organisation's improvement in patent management capability (PMC) and identify the resource required for progressing to the next maturity level. The integrated framework of the proposed PMMM draws on the CMMI (Selleri Silva et al., 2015) and modular construction for maturity approaches in the field of PM (Wustmans et al., 2019). Additionally, the Edison pyramid model (Harrison and Sullivan, 2011), strategic PMMM (Kern and van Reekum, 2012), AIDA maturity model (Petit et al., 2011), intellectual asset governance model (Gibb and Blili, 2012, 2013), PMMM (Nijmanting, 2015), and 7D PMMM (Moehrle et al., 2017) are important references that have contributed to our model. However, based on well-designed research method and extensive considerations, the model given in this study constitutes a commercial evaluation tool with prospective applications, which is fully detailed from the top-level model construction to grounded quantitative measurement findings. Furthermore, the results of this study have the potential to conceptually expand research beyond its present focus on the size of a firm's patent portfolio to a capacity-based view on PM.

Figure 1 Research gaps, goal and questions (see online version for colours)



In the case of developing countries like China, PM scenarios are improving but still in its infancy stage. China has made significant legislative amendments to its patent law four times (in the early 1990s, early 2000s, around 2008, and in 2020) to align with, and in some areas even surpass, international intellectual property (IP) law. Recent developments include the establishment of strong enforcement mechanisms and dynamic reforms in the judicial system, such as the creation of the IP Tribunal of the Supreme People's Court and the Special IP Courts in Beijing, Shanghai, Guangzhou and Hainan (Hong et al., 2022). These positive improvements have enabled Chinese industry to diversify its commercial operations, embrace global competition, and create a conducive climate for many large internationally-oriented companies to build global R&D centres in China. However, in order to achieve long-term economic growth and high-quality development, Chinese industries are under pressure to upgrade and transform their industrial structure. As part of their efforts, Chinese companies and the government have been actively working towards building efficient and standardised PM processes to leverage and extract value from intellectual assets, thereby driving innovation (Cao and Zhao, 2013). PM is evolving into a strategically important field for innovation-oriented businesses in China. Consequently, there is a need to examine the deployment and practice of PM in China, with the results of such observation serving as a reference for industries and enterprises in other countries.

The rest of the paper is structured as follows. After reviewing the literature including PMC and PMMM in Section 2, we explain the approaches used in the construction of PMMM in Section 3. Section 4 describes a double cases survey and its findings to illustrate how the model works. Section 5 concludes with conclusions, implications and limitations.

2 Literature review

2.1 PM: a capability-based perspective

The resource-based theory (RBT) considers firms as idiosyncratic and heterogeneous bundles of assets and resources (Wernerfelt, 1984). The key to a firm gaining sustained competitive advantage is the possession of valuable, rare, inimitable and non-substitutable (VRIN) resources (Barney, 1991). These VRIN features limit the market options available to a firm and ensure that the firm earns above-normal rates of return (Mahoney and Pandian, 1992). In the context of RBT, patents provide owner firms with a competitive edge due to the distinctiveness of their superior resources (Cao and Zhao, 2013). Being a manifestation of intellectual capital, patents are imperfectly mobile and heterogeneous in nature based on their appropriability (Shen and Shang, 2014), and their 'isolating' effect on imitation makes them consistent with the RBT's ex post limits to competition: imperfect substitutability (Peteraf, 1993; Teece, 2000). Furthermore, patents can also serve as a signalling function by eliminating informational imperfections in factor input markets (Hsu and Ziedonis, 2013). Accordingly, RBT perceives patents as a significant resource for organisational capability building.

Overcoming the static nature of RBT, the DCV places an emphasis on the evolution of resources and capabilities, and attempts to explain how firms can address rapidly changing surroundings by refreshing and creating VRIN resources (Ambrosini and Bowman, 2009). A dynamic capability is defined as "the firm's ability to integrate, build, and reconfigure internal and external competences" (Teece et al., 1997). Teece (2007) stresses that within fast-changing technological regimes, dynamic capabilities enable businesses to capture the key variables and relationships that need to be 'manipulated' to create, deploy, and protect the intangible assets, thereby sustaining superior long-term performance and avoiding the zero-profit trap. Recently, Marín-Vinuesa et al. (2023) highlighted the importance of developing a dynamic capability to integrate and combine a firm's patent-related resources and competencies. According to Saksupapchon and Willoughby (2021), the complexity of the business of technological innovation, not to mention the complexity of patent law, has evolved to the point where it must now be dynamically integrated with firms' evolving growing business models and corporate strategy. Drawing from the capability-based positions, we describe PMC as a particular dynamic capability that firms intentionally nurture to manage patent assets. PMC's strategic importance arises from its capacity to reconfigure and hone the technological, legal, and commercial procedures that generate, protect and utilise patents both within and outside of the firms' boundary in response to changes in broader business environment (Reitzig and Puranam, 2009; Ernst et al., 2016). PMCs are founded in high-level patent-based routines (Soranzo et al., 2017; Saksupapchon and Willoughby, 2021), entrenched in its underlying intangible attributes (Agostini et al., 2022a), and conditioned by technology-, firm-, and industry-specific variables (Ernst et al., 2016; Möhrle et al., 2018), leading to path dependencies (Saksupapchon and Willoughby, 2021). In other words, PMC is a potentially multidimensional construct that can be examined or quantified through patent-related processes that permit reconfiguration and realignment (Cao and Zhao, 2013). Therefore, from the perspective of DCV, the core components of PMCs, including strategy, people, activities, and decision rules, as well as organisational structure and culture (Teece, 2007), are visible elements of the PMCs.

Building upon the argument presented above, our focus lies on the dynamic and evolutionary nature of PMCs. Existing literature suggests that a firm's PMC may evolve over time, progressing through distinct generic phases. For instance, Yang and Minutolo (2016) argue that firms need to acquire and develop necessary resources, as well as make strategic decisions, to achieve an appropriate patent portfolio mix in dynamic environments. Soranzo et al. (2017) adopt an action research approach to investigate how a firm might make a dynamic change from the first level of PM ('defensive') to the second ('cost control'). This approach focuses on the patent planning and patent assessment process, considering critical factors such as major concerns and information demands, new product development, organisational arrangements, tools and methods employed to advance to the next level. In an empirical quantitative study of two prominent companies in the commercial aircraft industry, Saksupapchon and Willoughby (2021) propose a generic competition-influenced evolutionary pattern of patent application strategies, encompassing three developmental stages: passive strategies in the early phase, aggressive strategies in the growth phase and sophisticated strategies in the maturity phase. However, previous contributions have only offered sporadic proof of PMC's efficacy in achieving strategic business goals. Indeed, PMC is typically more complicated than other types of common capabilities, as it necessitates rare expertise inside the organisation or industry, significant lead times for construction, highly uncertain outcomes, and a substantial commitment of resources.

2.2 Patent management maturity models

The PMMMs are developed to surmount the static nature and capability rigidity of innovation performance assessment frameworks and can provide holistic views of PM development process by assessing the extent to which PMC is explicitly defined, understood and analysed. The fundamental concept of PMMMs draws inspiration from the capability maturity model (CMM) introduced by Paulk et al. (1993), which describes the evolutionary stages of software development processes in terms of maturity levels, facilitating improvements in process quality. CMM distinguishes five levels of maturity for software development processes: initial, repeatable, defined, managed, and optimised, that can be achieved by organisations through implementing continuous changes. The staged structure of the maturity model aims at guiding organisations to strive for the targeted maturity level in a gradually progressive manner during PM development (Moehrle et al., 2017).

The present PMMMs typically comprise two significant modules relating to

1 the object of analysis (describing the capabilities or elements corresponding to PM related functions and/or practices)

2 the subject of analysis (characterising the stages or levels of development of the organisation to be analysed and improved) (Wustmans et al., 2019).

Drawing from general systems terminology, the identified key capabilities (or elements) with similar attributes are integrated into the same categories or dimensions that serve different analytical or research purposes of the model or framework under consideration. For instance, Kern and van Reekum (2012) built a strategic PMMM based upon eight patent functions from a managerial perspective and four well-known strategic planning attitudes proposed by Ackoff (1981). These functions are divided into

1 inherent functions (incentive, appropriation, protection, and dissemination), interpreted as the purpose of establishing and maintaining relations in business

2 attribute functions (liability, asset, portfolio component, and performance indicator), namely the legal environment to managers, expected by the designers of patent systems.

Each function is described in four maturity levels: inactive, reactive, active, and proactive, which represent an increasing level of activeness. Following Kern and van Reekum's (2012) framework, Nijmanting (2015) further refined the strategic PMMM by redesigning the liability function based on three concepts (freedom to operate, liability of newness, and financial liability). The novel model was used to measure patent function performance for patent-intensive companies.

Petit et al. (2011) developed an IP diagnostic tool dedicated to small and medium size enterprises (SMEs) based on the marketing and sales AIDA approach. Their model converted the attention, interest, desire, and action (AIDA) levels to IP maturity levels (awareness, protection, management, and exploitation). In addition, they constructed an AIDA grid with 16 elements to structure the questionnaire for the assessing IP practices in enterprises. While this progressive model facilitates presenting IP audit results from various perspectives, it poses a significant challenge as it requires company directors to allocate a substantial amount of time for interviews (Enjolras et al., 2015). Harrison and Sullivan (2011) developed an Edison pyramid (or value hierarchy) approach to categorise PMM into five levels: defending position (level one), managing costs, capturing value, synthesising opportunities, and shaping the future. Each value hierarchy contains two to four elements, totalling 18, implying that organisations should prioritise different IP elements based on their current maturity level. Gibb and Blili (2012) introduced a comprehensive maturity model for intellectual asset, which is based on two dimensions (operational and strategic) and 12 elements. This model facilitates to characterise the increasingly sophisticated governance behaviour of SMEs. It also incorporates a five-stage PMM path consisting of dormant, ad-hoc, dynamic, ambitious, and pioneering (Gibb and Blili, 2013). It is worth noting that most published PMMMs adopt a five-level maturity structure.

Moehrle et al. (2017) conducted a recent study aiming to comprehensively assess the level of PMM with more complete and accurate dimensions and elements. They identified a total of 25 capabilities clustered into seven dimensions: portfolio, generation, intelligence, exploitation, enforcement, organisation, and culture. Each dimension is described in five maturity levels: neglector, starter, intermediate, performer, and conductor. Moehrle et al. (2017) recommend that an organisation should strive for the maturity level which best suits its resources, but it is not necessary to be the highest maturity level for each element. The 7D PMMM offers companies support for targeted improvement of PM functions and capabilities and opens up the possibility of identifying potential for improvement within and between companies (Möhrle et al., 2018). Following this, Wustmans (2019) dedicated a PhD thesis to the development and application of a 7D PMM. The thesis includes four case studies in medium-sized technology-oriented companies, focusing on the one hand on strategic managers and on the other hand on those responsible for patent intelligence as respondent groups. Through open interviews and workshops, the author gives an impression of the way in which the dimension of patent intelligence in particular is shaped in different companies. More

recently, Wustmans et al. (2019) reviewed existing maturity approaches in the field of PM and IP management. They identified six different analytical categories for characterising maturity approaches: system, phasing, relatedness, focus, type, and representation. Furthermore, they demonstrated how these approaches can be enriched by other methods based on their modular structure which informs our model construction.

3 Construction of the proposed PMMM

3.1 Components of the model

To establish and refine the PMMM, this study adopts two exploratory techniques – literature analysis and experience survey. The initial framework of the model was developed based on an extensive literature review and the researchers' own experience with multiple companies. The study also examines the evolution of corporate PM development by reviewing previous research. The experience survey focuses on interviewing 18 IP managers or directors and their representation of Chinese PM perspectives is evidenced. Since 2011, the China International Annual Forum has organised the annual meeting of in-house IP managers in China. During one of these sessions, one of the authors presented the preliminary framework of the PMMM to senior managers and discussed the importance of establishing a new framework with them. These managers are specialist practitioners in the realm of PM and hold executive positions in IP/PM at prominent firms across China (e.g., Beijing, Shanghai, Shenzhen, Guangzhou, Hangzhou, and Suzhou). All these experts have a minimum of eight years of PM expertise. The interviews with these experts provided a comprehensive understanding of their overall perception of the study, including its seven dimensions and 24 elements. After two rounds of interactive improvement, the experts validated that the model was objective, the PMC was a logical new sight, and the framework was clear and methodical. Ultimately, the study integrated the core components of PMCs and identified seven dimensions: culture and system, organisation, intelligence, generation, layout, protection, exploitation and operation. Each dimension contains two to four key elements with similar attributes (Tables 1–7), which collectively define a company's overall PMM.

The elements within the culture and system dimension pertain to the organisational environment that influences PM activities. Beyond hard factors such as technologies, techniques, and people, a firm's success is also influenced by soft factors like corporate strategy formulation and employee awareness. These factors have a significant impact on the output of high-value patents to some extent (Bhatt, 2001). A lack of PM awareness among leaders can hinder the overall progress of PMC (Soranzo et al., 2017). Firms often undertake patent-related initiatives to enhance employee awareness, involvement in patenting, and stimulate willingness and creativity for innovation and invention. This includes managing inventor evaluation and reward systems more accurately, as well as implementing R&D incentive systems for patent applications (Jell, 2011). The integrated and supportive nature of culture and system necessitates the combination of technological, legal, and management resources and capabilities to create an enabling environment for leveraging opportunities and responding to patent threats (Agostini et al., 2022a).

Table 1 Validated culture and system dimension and its elements

Dimension	*Element*	*Definition*	*References*
Culture and system	Awareness	The extent to which a firm' have adopted and are committed to a culture of patent creation, protection and exploitation to enable an effective patent management.	Moehrle et al. (2017), Wustmans et al. (2019) and Agostini et al. (2022a)
	Strategy fit	The degree to which patent strategy is in line with the overall corporate and business strategy or other IP (such as trade secret, trademark or copyright) strategies and adapt in response to changes in the business environment for achieving the company's vision and mission.	Soranzo et al. (2016, 2017), Wustmans et al. (2019), Grzegorczyk (2020) and Agostini et al. (2022b)
	Motivation	Incentive schemes for employees used to drive a proactive and enthusiastic environment to stimulate inventiveness in order to capture opportunities for increasing potential for value creation.	Soranzo et al. (2016), Conegundes De Jesus and Salerno (2018) Wustmans et al. (2019) and Agostini et al. (2022a, 2022b)

Table 2 Validated organisation dimension and its elements

Dimension	*Element*	*Definition*	*References*
Organisation	Structure and function	Patent department's closeness to a firm's headquarters and whether it can properly handle patent-related issues including generation, protection, exploitation and operation, etc.	Jell (2011), Soranzo et al. (2017) and Agostini et al. (2022a, 2022b)
	Personnel allocation	Professionalism of patent manager or patent liaison persons and allocation of responsibilities regarding patents within a firm.	Tsuji (2002), Jell (2011) and Agostini et al. (2019)
	Business sector coordination	Ensuring the optimal integration of patent-related matters between patent department and other corporate divisions (e.g., R&D, production, marketing, purchase, and finance).	Reitzig and Puranam (2009), Jell (2011), Jell et al. (2015), Ernst et al. (2016), Soranzo et al. (2016), Moehrle et al. (2017) and Wustmans et al. (2019)
	Stakeholder engagement	The degree to which an enterprise can utilise resources from external stakeholders (e.g., government, universities, patent agencies, law firms, asset appraisal agencies or other firms) involved in patent management include: • Striving for policy privilege to create high-value patents, reduce operating costs or promote the utilisation of patent assets.	Jell (2011), Ernst et al. (2016), Wustmans et al. (2019) and Jee and Sohn (2020)

Table 2 Validated organisation dimension and its elements (continued)

Dimension	*Element*	*Definition*	*References*
Organisation	Stakeholder engagement	• Outsourcing the drafting and filing of patent applications to external attorneys. • Taking advantage of universities' scientific and technological achievements to complement or perfect firm' patent portfolio.	Jell (2011), Ernst et al. (2016), Wustmans et al. (2019) and Jee and Sohn (2020)

Table 3 Validated intelligence dimension and its elements

Dimension	*Element*	*Definition*	*References*
Intelligence	Technical analysis	Predicting or capturing the trend of upcoming or trendy technologies by monitoring for patent information to find new market opportunity and to identify potential threats to the focal business.	Jell et al. (2015), Madani and Weber (2016), Ernst et al. (2016), Soranzo et al. (2016, 2017), Song et al. (2017), Wustmans et al. (2019), Krestel et al. (2021) and Agostini et al. (2022a)
	Legal analysis	Firms' ability to analysing whether R&D initiatives, new products or technologies implemented by itself infringe the claims of granted patents or patent applications under examination owned by others to ascertain patent clearance or avoid patent infringement.	Ernst et al. (2016), Lee and Lee (2017), Soranzo et al. (2017), Agostini et al. (2019, 2022a, 2022b)
	Competitor analysis	Firms' success in screening for information about competitors' market orientation and patenting intentions for flexibly coping with competitive challenge.	Jell (2011), Ernst et al. (2016), Soranzo et al. (2016), Lee and Lee (2017), Ernst (2017), Conegundes De Jesus and Salerno (2018) and Wustmans et al. (2019)
	Archives management	Ensuring that patent-related documents involving R&D process and outcome documentations, patent applications, and communication protocols, external technical intelligence, competitor developments, management process records, contracts (in particular licence and non-disclosure agreements) are properly circulated and utilised to serve as important sources of a firm's strategic decision-making, and to be used for current and future R&D projects.	Lagemaat (2005), Jell (2011), Ernst (2017) and Denter et al. (2023)

Table 4 Validated generation dimension and its elements

Dimension	*Element*	*Definition*	*References*
Generation	Mining	Firms' success in effectively determining candidate patents, developing technology, and applying for patents upon completion, and considering how to market inventions for commercialisation by establishing close interactions between Patent Liaison Officers and researchers.	Tsuji (2002), Roy and Sivakumar (2011) Schmidt (2013) and Ernst (2017)
	Design around	Designing similar solution based on competitive but not equivalent to the existing patents (e.g., trimming or substituting one or more technical feature(s) claimed in the claims; or using evolution trends of technical features to achieve same or better function) in order to avoid patent infringement.	Li et al. (2015) and Moehrle et al. (2017)
	Draft management	Firms' ability to manage activities from invention to application, and structuring of the process (e.g., identifying all of the firm's inventions that are patentable, and deciding which applications will be drafted and processed internally and which ones will be outscored to external patent attorneys).	Roy and Sivakumar (2011), Jell et al. (2015), Moehrle et al. (2017), Soranzo et al. (2017) and Wustmans et al. (2019)

The organisation dimension focuses on the integration of PM within a firm's organisational structure. PM responsibilities span from internal resources geared at providing patent owners with an appropriation advantage to build a stronger market position, to external patent transactions and litigation. PM-advanced organisations typically feature well-structured patent departments to handle specialised and complicated PM duties, such as drafting patents, building patent portfolios, and responding to litigation (Jell, 2011). PM duties are often arranged cross-functionally, with personnel from various departments collaborating to coordinate operations, playing a crucial role at the intersection of multiple departments (Ernst et al., 2016). Therefore, in order to effectively fulfil both internal and external responsibilities, PM departments must collaborate across multiple functions (Reitzig and Puranam, 2009).

The main task of the Intelligence dimension is to identify and extract relevant information from patent documents to assist managers in eliciting key insights, monitoring rivals, developing R&D plans, and optimising patent portfolios (Ernst et al., 2016; Soranzo et al., 2016). However, the significant increase in the volume of patent literature poses considerable challenges for patent intelligence analysis. To address these challenges, more advanced patent analysis technologies, including patent network analysis, deep learning, and text mining, are frequently used to monitor the technical and legal status of patents of interest, as well as to identify patterns in technological development and competitor threats (Madani and Weber, 2016; Yang et al., 2021; Krestel et al., 2021).

Table 5 Validated layout dimension and its elements

Dimension	*Element*	*Definition*	*References*
Layout	Application strategy	Firms' ability to protect an invention in alignment with the business strategy by making decisions on what, when and where to file for a patent based on the risk/reward trade-offs in a target- and utility-oriented way.	Schmidt (2013), Soranzo et al. (2016), Moehrle et al. (2017), Wustmans et al. (2019), Yang et al. (2021) and Agostini et al. (2022a)
	Portfolio optimisation	Refining, updating, and building a complete and sustainable combination by means of in-house R&D and development and external acquisition, such as technology in-licensing, collaborative R&D, technology purchasing (e.g., technology purchasing), joint ventures, acquisition of innovative firms (or business units), etc.	Holgersson and Granstrand (2017), Conegundes De Jesus and Salerno (2018), Wustmans et al. (2019), Agostini et al. (2019), Li et al. (2020) and Agostini et al. (2022a, 2022b)
	Classification	Firms' ability to manage both patent applications and already granted patents by longitudinally identifying the value of each sufficiently and accurately, and categorising horizontally the patents by buckets such as project types, markets, technologies, innovation degree or product lines.	Soranzo et al. (2016), Yang and Minutolo (2016), Soranzo et al. (2017) and Conegundes De Jesus and Salerno (2018)
	Maintenance	Define the divestment strategy for abandoning or donating pending or granted patents by withdrawal or non-payment of annual fees to avoid unnecessary patent maintenance costs.	Jell et al. (2015), Soranzo et al. (2016, 2017), Conegundes De Jesus and Salerno (2018), Wustmans et al. (2019) and Grzegorczyk (2020)

Table 6 Validated protection dimension and its elements

Dimension	*Element*	*Definition*	*References*
Protection	Preventing infringement	Firms' flexibility and agility in reacting in cases of patent infringement by third parties once infringement is detected, which include informing the infringer by cease and desist letter, negotiating licences, litigating, and, if necessary, coordinating the preparation of a response to patent invalidity and defending the focal firm's patents.	Jell (2011), Jell et al. (2015), Ernst et al. (2016) and Wustmans et al. (2019)
	Crisis response	Firms' reaction to being accused of patent infringement in terms of the preparation of counter-measures involving reconciliation, legal defence, invalidating the owners' patent(s), or countersuing the attacker.	Jell (2011), Jell et al. (2015), Moehrle et al. (2017) and Wustmans et al. (2019)

Table 7 Validated exploitation and operation dimension and its elements

Dimension	*Element*	*Definition*	*References*
Exploitation and operation	Industrialisation	The internal use of a firm's existing patents for protecting products or processes manufactured to avoid imitation by competitor and to capture more market share.	Choi and Kim (2018), Agostini et al. (2022b) and Denter et al. (2023)
	Commodification	The external commercialisation of a firm's existing patents to generate a source of income outside the firm boundaries through licensing-out, cross-licensing, or selling patents, which can be achieved by improving the attractiveness of the organisation, contacting with potential partners, negotiating licensing or transferring agreements, or developing business models around franchising.	Ziegler et al. (2013), Ernst et al. (2016), Soranzo et al. (2016), Moehrle et al. (2017), Holgersson and Granstrand (2017) and Wustmans et al. (2019)
	Capitalisation	Firms' ability to monetise patent assets in alignment with the goals of obtaining business finance from private/institutional investors or lenders, venture capitalists, specialised/regular banks by equity stakes, insurance, securitisation, trust and pledge.	Kern and van Reekum (2012) and Soranzo et al. (2016)
	Marketing and reputation	The social status and the respect of others perceived by a firm's key stakeholders (e.g., suppliers, investors, customers, employees and members of the media) by publication of patent information in order to establish quality reputations for differentiated acts and products.	Holgersson (2013), Soranzo et al. (2016), Moehrle et al. (2017) Conegundes De Jesus and Salerno (2018)

The generation dimension deals with acquisition of patents in the context of R&D activities whereby patent rights are obtained, including the process from R&D to patent application, such as invention creation, drafting and filing of patent applications. In cases where an organisation lacks the capacity to generate patents internally, it may opt to acquire patents from third parties in the secondary market to supplement its patent portfolio. There have been explicit conversations about the benefits and drawbacks of the 'make or buy' option (Jell, 2011). Outsourcing enables firms to overcome limitations in technical staff capacity, and in an open innovation environment, purchased patents often tend to be more complex and technologically advanced than those created in-house (Roy and Sivakumar, 2011). However, this practice is also associated with long-term costs and risks. For example, outsourcing may result in the loss of R&D knowledge on prior art, which is crucial for accurately accurately determining the boundaries of patent rights (Reitzig and Wagner, 2010).

The layout dimension addresses the critical concerns of a company's patenting strategy and patent portfolio optimisation in order to balance the costs and benefits associated with patents. A patent portfolio can be considered as a strategic combination of individual patents that are distinct yet interconnected (Li et al., 2020). Firms should make logical decisions about whether or not to patent based on their potential for improving their competitiveness. Similarly, ongoing assessment of whether patents still warrant payment of maintenance fees is crucial (Soranzo et al., 2016). Several factors influence patent layout, including the size of the firm, industry structure, and competitor behaviour (Somaya, 2012). For instance, large corporations often have the resources required to establish a systematic patent portfolio, while SMEs may focus on obtaining individual patents to safeguard their ideas (Grzegorczyk, 2020).

The protection dimension entails questions about the employment of legal alternatives as a result of patent disputes. Patent litigation is a common method employed by firms to enforce their patents against rivals, but it is also regarded as a costly and complex multi-stage game (Somaya, 2012). Companies find themselves in both plaintiff and defendant roles in patent litigation, as they often fear reprisal when engaging in aggressive litigation to suppress their competitors (Chih-Yi and Bou-Wen, 2021). Therefore, it is equally important to identify both the company infringing its own patent rights and the company initiating the patent attack. In the event of infringement, a firm can choose to ignore it (as the law does not protect those who slumber in power) or assert its rights by seeking a licence and a court injunction. For organisations that are more susceptible to being sued, it is critical to actively plan tactics to counter-suit the adversary (Jell, 2011). Ex ante negotiating and cross-licensing are often considered successful methods for avoiding patent disputes.

The exploitation and operation dimension addresses the issue of how patents are utilised internally and commercialised externally. Industrialisation establishes the rights boundaries of technology by incorporating patents into goods or manufacturing processes (Choi and Kim, 2018). Patent holders can regard their patents as marketable assets that can be externalised to another independent entity for monetary or non-monetary compensation (Somaya, 2012). There are several avenues available for patent holders to effectively extract value from their patents, such as sales, out-licensing, and cross-licensing (Soranzo et al., 2016). In particular, cross-licensing is often recommended as a means to facilitate freedom of operation when both parties aim to commercialise their inventions without incurring any costs or danger of litigation (Grzegorczyk, 2020).

3.2 Maturity levels

It is critical to first comprehend the level of maturity before assessing an organisation's PMC. According to Dooley et al. (2001), maturity is defined as "the degree to which a process is defined, managed, measured, and continuously improved." Also, it can be understood as the quality or state of being mature in performing a task to gain a brilliant outcome (Alghail et al., 2021). Besides, it can be interpreted as the attainment of a higher level of sophistication or proficiency in a specific domain within an organisation (Irfan et al., 2020). In this study, maturity is defined as the continuous growth of PM practice, strategy and decision-making, indicating that an organisation progresses through maturity levels over time until it achieves the highest level. Consequently, the PMMM comprises a flexible sequence of maturity levels with a set of maturity parameters from the lowest to the highest that indicate an expected and desired evolution route of advancement through

discrete stages. The route's bottom stage represents an initial state, characterised by a lack of any capability. At the highest level, an organisation's PMC are at its most mature.

Table 8 Maturity levels of the elements

Element	*Maturity level*
Awareness	The competence has not been considered yet.
	Minority of employees are active in participating in patent-related issues.
	Half of employees are active in participating in patent-related issues.
	Majority of employees are active in participating in patent-related issues.
	All employees are eager to participate in patent-related issues.
Strategy fit	Patent strategy is not in line with the overall corporate and business strategy and lacks response to changes in the business environment.
	Patent strategy is minimally in line with the overall corporate and business strategy and lacks response to changes in the business environment.
	Patent strategy is somewhat in line with the overall corporate and business strategy and is lagging behind the changes in the business environment.
	Patent strategy is highly in line with the overall corporate and business strategy and is able to response to changes in the business environment.
	Patent strategy is completely in line with the overall corporate and business strategy and is able to response to changes in the business environment timely.
Motivation	The competence has not been considered yet.
	There are few incentive schemes, which is difficult to stimulate the inventiveness of employees.
	There are some incentive schemes, which can appropriately stimulate the inventiveness of employees.
	There are many incentive schemes, which can effectively stimulate the inventiveness of employees.
	There are systematic incentive schemes, which can sufficiently stimulate the inventiveness of employees.
Structure and function	The competence has not been considered yet.
	Patent department is non-centrally located under the R&D department and headed by a senior engineer, or a scientist.
	Patent department is non-centrally located parallel to the R&D department and headed by a senior engineer, or a scientist.
	Patent department is centrally located higher than the R&D department and headed by a patent attorney.
	Patent department directly subordinate to the (vice) president and headed by a senior patent attorney.
Personnel allocation	No patent manager or patent liaison persons.
	1~2 (un)professional patent managers or patent liaison persons.
	3~5 patent managers or patent liaison persons.
	6~20 patent managers or patent liaison persons.
	More than 20 patent managers or patent liaison persons.

Table 8 Maturity levels of the elements (continued)

Element	*Maturity level*
Business sector coordination	No connection and no integration.
	Scarce connection without integration.
	Frequent connection without integration.
	Frequent connection with proper integration.
	Good mechanism with efficient integration.
Stakeholder engagement	The competence has not been considered yet.
	Less proficient in leveraging the resources of few stakeholders.
	Proficient in leveraging the resources of few stakeholders.
	Proficient in leveraging the resources of some stakeholders.
	Extremely good at leveraging the resources of many stakeholders.
Technical analysis	The competence has not been considered yet.
	There are some non-relevant or non-dedicated occasional technical analysis in the firm.
	There are some relevant or dedicated occasional technical analysis in the firm.
	There are relevant or dedicated periodical technical analysis in the firm.
	There are routine relevant or dedicated technical analysis in the firm.
Legal analysis	The competence has not been considered yet.
	Legal analysis can marginally avoid being accused of patent infringement.
	Legal analysis can moderately avoid being accused of patent infringement.
	Legal analysis can highly avoid being accused of patent infringement.
	Legal analysis can completely avoid being accused of patent infringement.
Competitor analysis	Firm has had no success in screening for information about competitors' market orientation and patenting intentions.
	Firm has had little success in screening for information about competitors' market orientation and patenting intentions.
	Firm has had success in 1 out of 3 (screening for information about competitors' market orientation and patenting intentions).
	Firm has had success in 2 out of 3 (screening for information about competitors' market orientation and patenting intentions).
	Firm is successful in screening for information about competitors' market orientation and patenting intentions.
Archives management	The competence has not been considered yet.
	Patent-related documents are sporadically managed without circulation and utilisation.
	Patent-related documents are sporadically managed with circulation and utilisation.
	Patent-related documents are efficiently managed with circulation and utilisation.
	Patent-related documents are highly efficiently managed with flexible circulation and utilisation.

Table 8 Maturity levels of the elements (continued)

Element	*Maturity level*
Mining	No support to determine candidate patents, developing technology, and applying for patents upon completion.
	Little support to determine candidate patents, developing technology, and applying for patents upon completion.
	Some support to determine candidate patents, developing technology, and applying for patents upon completion.
	Much support to determine candidate patents, developing technology, and applying for patents upon completion.
	Full support to determine candidate patents, developing technology, and applying for patents upon completion.
Design around	The competence has not been considered yet.
	Firm has had success in designing similar solution based on competitive but not equivalent to the existing patents as a result of added cost with compromising function.
	Firm has had success in designing similar solution based on competitive but not equivalent to the existing patents with compromising function.
	Firm has had success in designing similar solution based on competitive but not equivalent to the existing patents without compromising function.
	Firm has had success in designing similar solution based on competitive but not equivalent to the existing patents as a result of increased maturity, learning, continuous improvement without compromising function.
Draft management	The competence has not been considered yet.
	Unordered management and implementation without a clearly-defined aim.
	Unordered management and implementation with a clearly-defined aim.
	Some ordered management and implementation with a clearly-defined aim.
	Ordered and effective management and implementation with a clearly-defined aim.
Application strategy	The competence has not been considered yet.
	Firm files patents based on non-competitive needs to obtain exclusive right as fast as possible.
	Firm files patents based on its own needs and seeks defensive expansion.
	Firm selectively files patents based on its own strategic needs and external competitors.
	Firm systematically files patents based on the development trend of the industry.
Portfolio optimisation	The competence has not been considered yet.
	Firm constructs a less rigorous patent portfolio.
	Firm constructs a somewhat rigorous patent portfolio.
	Firm constructs a highly rigorous patent portfolio.
	Firm constructs a completely rigorous patent portfolio.

Table 8 Maturity levels of the elements (continued)

Element	*Maturity level*
Classification	The competence has not been considered yet.
	There is no specific method or tool for assessing patent value and it is impossible to accurately classify patents.
	There are specific methods or tools to assess patent value, which can quantitatively classify patents.
	Regularly use specific methods or tools to assess patent value, and conduct accurate classification management of patents.
	Continue to use specific methods or tools to assess patent value, and systematically classify and manage patents from both quantitative and qualitative aspects.
Maintenance	The competence has not been considered yet.
	There are some non-scientific evaluation methods in making decision on whether to maintain the patents.
	There are some scientific evaluation methods in making decision on whether to maintain the patents.
	There are scientific evaluation methods in making decision on whether to maintain the patents.
	There are scientific evaluation methods and systematic systems in making decision on whether to maintain the patents.
Preventing infringement	The competence has not been considered yet.
	Firm has no readiness plans in terms of reactions to patent infringement and only reacts post-change.
	Firm aspires to increase flexibility and agility for preventing infringement but has no plans for different scenarios yet.
	Firm has plans for preventing infringement.
	Firm is proactive in terms of flexibility and agility for preventing infringement with a systematic plan/periodically reviewed.
Crisis response	The competence has not been considered yet.
	Less proficient in handling simple alleged infringement.
	Proficient in handling simple alleged infringement.
	Proficient in handling complicated alleged infringement.
	Extremely good at handling all kind of alleged infringement.
Industrialisation	No internal use of a firm's existing patents.
	Only a minority of firm's existing patents are used internally.
	Half of firm's existing patents are used internally.
	Majority of firm's existing patents are used internally.
	All firm's existing patents are fully used internally.
Commodification	No bargaining power and negotiation skills for external commercialisation.
	Little bargaining power and negotiation skills for external commercialisation.
	Some bargaining power and negotiation skills for external commercialisation.

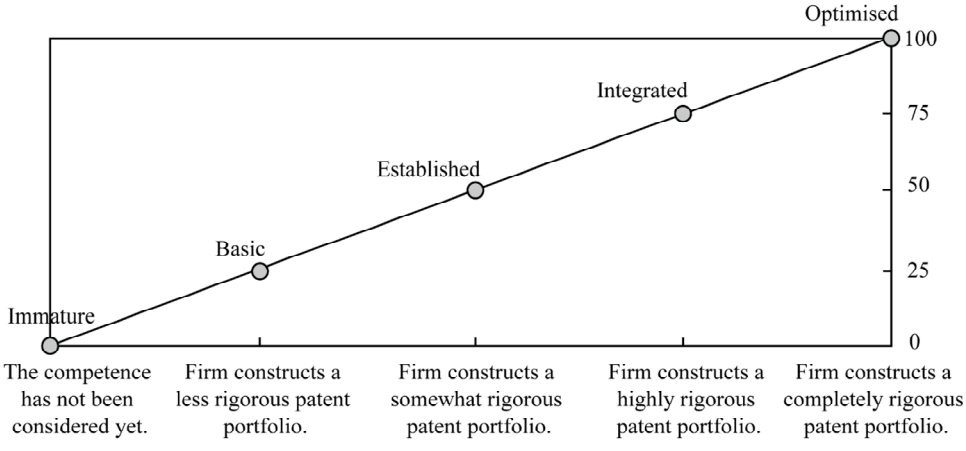
Table 8 Maturity levels of the elements (continued)

Element	*Maturity level*
Commodification	Good bargaining power and negotiation skills for external commercialisation.
	Strong bargaining power and negotiation skills for external commercialisation.
Capitalisation	Capitalisation of patent assets are not aligned with the goals of obtaining business finance.
	Capitalisation of patent assets are minimally aligned with the goals of obtaining business finance.
	Capitalisation of patent assets are somewhat aligned with the goals of obtaining business finance.
	Capitalisation of patent assets are highly aligned with the goals of obtaining business finance.
	Capitalisation of patent assets are completely aligned with the goals of obtaining business finance.
Marketing and reputation	The competence has not been considered yet.
	Unorganised publication of patent information make firm somewhat respected.
	Organised publication of patent information make firm respected.
	Organised publication of patent information is performed to establish quality reputations for differentiated acts and products.
	Organised and intended publication of patent information is performed to establish quality reputations for differentiated acts and products in mind.

As shown in Table 8, each element is categorised into five distinct maturity levels, ranging from the lowest to the highest: immature, basic, established, integrated and optimised. These levels correspond to their respective capabilities. To elaborate further, at level one, 'immature' PMCs lack a structured format and do not possess a framework for initiating and managing patent activities. The second level, 'basic', suggests that organisations may undertake fundamental patent operations using informal PM tools and breakdown structures. Moving on to the third level, 'established', it signifies that companies have implemented a formal and repeatable PM charter. Following that, the fourth level, 'integrated', demonstrates a firm's ability to integrate and coordinate diverse PM duties across different departments to assure PM performance while minimising schedule risks and legal disputes. Finally, the highest level of maturity, 'optimised', suggests that organisations possess a comprehensive view and vision to constantly optimise and enhance the overall integrated management of patent-related operations.

Furthermore, assignment curves are used to quantify the maturity levels of the elements. The precise quantitative value related to each element will be determined once the experts assess its current maturity level. The assignment curves approach facilitates the normalisation of measurement results by allowing experts to compare across all the criteria. These quantified metrics will be employed in the case studies presented in Section 4. Figure 2 presents an example of the assignment curves. The rest of the assignment curve values follow the same quintile procedure on a scale of 100.

Figure 2 Maturity levels and corresponding values for the portfolio optimisation element



3.3 Weights

We employed the analytic hierarchy process (AHP) method to assign unequal weights to each component. This method, initially proposed by Saaty (1990), is widely used to analyse decision-making problems with a hierarchical structure by achieving consensus among participants. It calculates the weights of each identified objective based on specific evaluation derived from the subjective judgment of relevant specialists.

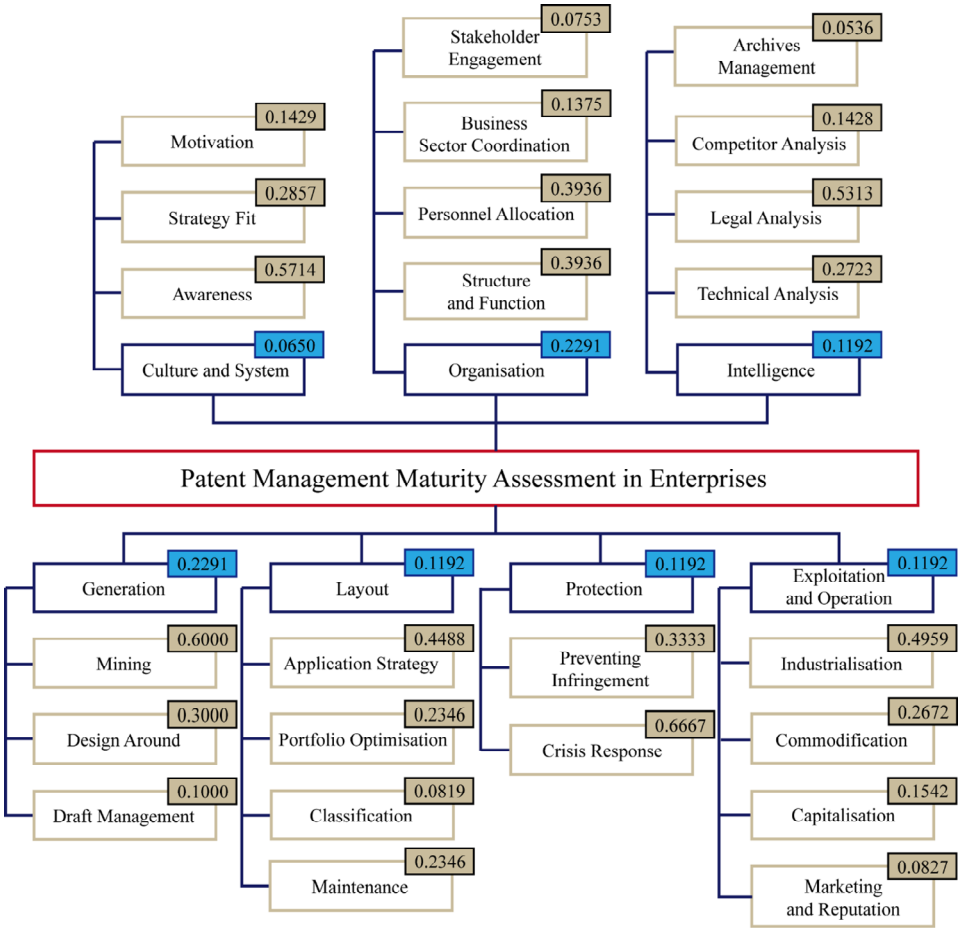
For the importance assessment of PMC maturity in enterprises, a group of IPR experts were required to assign weights to each component, which were subsequently integrated to assess the overall strength. The model tests conducted demonstrate strong internal consistency for each judgmental matrix, with all consistency ratio (CR) values significantly lower than 0.10. Figure 3 illustrates the global weights (GWs) assigned to each dimension and element, with both the organisation and generation dimensions playing prominent roles, each with a GW of 0.2291. It is evident that IPR experts consider an efficient organisation and a well-developed patent generation system as solid foundations for shaping a company's PMM, as the organisation that can effectively coordinate internal and external matters ensures the functioning of the PM system while the generation of patents underpins the other dimensions.

4 Case study

This section provides practical cases of how to use the PMMM through quantification and assignment curves. We chose two manufacturing companies from distinct industries on purpose, one from the materials industry and the other from the automotive sector. To ensure confidentiality, anonymous companies were chosen to participate in the model validation. Company I, located in Hangzhou, Zhejiang Province, has engaged in R&D activities for over ten years, and its environmentally friendly bio-composite products are supplied to various nations worldwide. The company possesses an engineering research centre and over 300 patents (including over ten patent families), the majority of which have been commercialised. Company II has been involved in the autonomous driving

business for over 20 years, delivering innovative solutions to automotive manufacturers. This company has a huge number of collaborations with internationally renowned automotive manufacturers, with over 800 R&D workers and four R&D facilities.

Figure 3 Composition and weight allocation of the PMMM (see online version for colours)



Extensive surveys and interviews were undertaken with the directors of both corporations' patent departments. PM executives, well-versed in their respective company's PM operations, are eager to assist us in quantifying the maturity level of all aspects. Each element' score is calculated by multiplying its GW by the value (D) of its actual maturity level from the assignment curve, and the results of all elements are then added together to calculate the overall PMM score. The PMM scores for Company I and Company II were determined as 63.325 (level 3) and 33.596 (level 2) respectively (refer to Table 9). These results can assist in assessing a company's current PMM, quantifying its position, and providing guidance on the next steps in identifying targets and allocating resources for improving the company's PMC.

Table 9 Case study results (see online version for colours)

Dimension	*P weight*	*Element*	*Local W*	*Global W*	*Case I*		*Case II*	
					D score	*Score = GW * D*	*D score*	*Score = GW * D*
Culture and system	0.0650	Awareness	0.5714	0.0372	50	1.857	50	1.857
		Strategy fit	0.2857	0.0186	75	1.395	75	1.395
		Motivation	0.1429	0.0093	25	0.233	75	0.698
Organisation	0.2291	Structure and function	0.3936	0.0902	75	6.765	25	2.255
		Personnel allocation	0.3936	0.0902	25	2.255	25	2.255
		Business sector coordination	0.1375	0.0315	75	2.363	75	2.363
		Stakeholder engagement	0.0753	0.0173	100	1.725	75	1.294
Intelligence	0.1192	Technical analysis	0.2723	0.0325	50	1.625	50	1.625
		Legal analysis	0.5313	0.0633	50	3.165	50	3.165
		Competitor analysis	0.1428	0.0170	75	1.275	0	0.000
		Archives management	0.0536	0.0064	50	0.320	75	0.480
Generation	0.2291	Mining	0.6000	0.1375	75	10.313	50	6.875
		Design around	0.3000	0.0687	75	5.153	0	0.000
		Draft management	0.1000	0.0229	50	1.145	50	1.145
Layout	0.1192	Application strategy	0.4488	0.0535	75	4.013	50	2.675
		Portfolio optimisation	0.2346	0.0280	50	1.400	25	0.700
		Classification	0.0819	0.0098	25	0.245	50	0.490
		Maintenance	0.2346	0.0280	50	1.400	25	0.700
Protection	0.1192	Preventing infringement	0.3333	0.0397	75	2.978	25	0.993
		Crisis response	0.6667	0.0795	50	3.975	0	0.000
Exploitation and operation	0.1192	Industrialisation	0.4959	0.0591	75	4.433	25	1.478
		Commodification	0.2672	0.0319	100	3.185	0	0.000
		Capitalisation	0.1542	0.0184	75	1.380	50	0.920
		Marketing and reputation	0.0827	0.0099	75	0.743	25	0.248
						63.325		33.596

In the first case, Company I demonstrates strong performance in terms of ‘stakeholder engagement’ and ‘commodification’. The company excels in integrating external resources, such as universities, research institutes, or other businesses, and collaborates

with them to accelerate patent development and utilisation. Additionally, Company I prioritises strengthening its patent mining capability and allocates substantial investments towards R&D efforts. This company's patent liaison persons and R&D professionals, in particular, collaborate with each other to develop patent portfolios tailored to the market, providing robust support for further commercialisation (Reitzig and Puranam, 2009). On the other hand, increasing professional 'personnel allocation' is one of the most significant chances to enhance the company's PMM, as this element has the second highest GW but a low maturity level. According to our survey, the company has only one PM manager and there is a need to strengthen their skills to satisfy the company's increasingly complex strategic goals. Additionally, the company has a lot of space for development in elements like 'motivation', 'classification' and 'crisis response'. Strengthening 'technical analysis', 'legal analysis' and 'archives management' are also important in combination with increasing PMM. Addressing these deficiencies can improve company's PMM and contribute to long-term performance.

Company II has a substantially lower PMM score compared to Company I. This company stands out for its capability in areas such as 'strategy fit', 'motivation', 'business sector coordination', 'stakeholder engagement', and 'archives management'. The patent managers of Company II effectively operate their own patent assets by establishing systems and coordinating both internal and external actors, specifically tailored to the technological characteristics of the automotive industry. However, Company II has limited PMM in the areas of 'competitor analysis', 'design around', 'crisis response', and 'commodification'. These aspects, although related, are not adequately addressed in relation to the competitive market challenges explicitly targeted by PM, as indicated in Table 9. We believe that as with Company I, the major cause for this discrepancy lies in the lack of PM employees, which is consistent with the company's low scores for 'personnel allocation' and 'structure and function'. Company II should focus on enhancing the maturity levels of the 'design around' and 'crisis response' elements, which carry significant weight but currently score low. Ex ante negotiation, without prior patent infringement, may obtain odds of licensing or selling patents in cases of commodification targeted at external exploitation of patents. Additionally, Company II could improve their PMM by addressing the 'portfolio optimisation' and 'maintenance' elements within the 'layout' dimension. Overall, Company II currently possesses a low PMM, and it should prioritise the improvement of weak but crucial components to gradually elevate its PMM.

Based on the case studies, following phases can be summarised for using the model: first, it is important to understand the background information of the organisation, including its industry, size, and organisational structure. Second, the current state of the organisation's PM should be identified and the organisation's PMM level should be quantified. Third, the target maturity level for improvement should be determined, taking into account the organisation's available resources. Fourth, measures should be developed to improve the organisation's PMM. Fifth, these improvement measures should be implemented.

By following these systematic processes, organisations can gain a comprehensive understanding of their strengths and identify areas that require further development. Since different elements of PMCs are interconnected and interact with one another, organisations should prioritise elements with higher weights and address weaker areas in order to improve overall PMM. When applied to the realm of comparable organisations,

the model enables a set of benchmarks to be framed. However, it is worth noting that the model established in this paper is useful, but not the only approach to measure a firm's PMM, as PM activities will be influenced by a variety of circumstances. Managers should adjust their capability composition accordingly and dynamically respond to changes in both internal and external environments.

5 Conclusions

Framed in the DCV and PM literature, this paper seeks to develop a comprehensive PMMM designed to support organisations to progressively analyse, understand and improve their PMM with three questions addressed:

1 What are the main dimensions and elements in the assessment of PMM in enterprises?

2 How to quantify maturity level of each element and provide a progressive approach for the continuous improvement in enterprises?

3 Does the proposed framework offer an effective and practical way to assess PMM in enterprises?

Based on a thorough literature analysis and an experience survey, we have integrated the core components of PMCs and identified seven dimensions, each of which contains two to four key elements with similar attributes. These components are founded in high-level patent-based routines, entrenched in its underlying intangible attributes, and conditioned by technology-, firm-, and industry-specific variables. For instance, the elements within the culture and system dimension relate to the organisational environment that influences the patent-related activities. The protection dimension entails questions about the employment of legal alternatives as a result of patent disputes. The exploitation and operation dimension addresses the issue of how patents are implemented internally and commercialised externally.

In response to question 2, we introduce the concept of maturity and define it as "a continuous growth of PM practice, strategy and decision-making, implying that an organisation progresses through maturity levels over time until it achieves the highest level." Each element within the PMM framework is assigned one of five different maturity levels: immature, basic, established, integrated, and optimised, based on its respective capabilities. This precise description of maturity levels facilitates a clear path for the continuous progression of a company's PMM. Furthermore, assignment curves are used to quantify the maturity levels of the elements, and the values follow a quintile procedure on a scale of 100. This allows professionals to normalise the measurement results across all criteria.

In response to question 3, we have chosen two manufacturing companies as examples to demonstrate the practical application and usefulness of the proposed model. The model's application can be summarised in five steps:

1 comprehend background information

2 determine the current state

3 determine the target maturity level

4 develop measures

5 implement improvement measures.

Throughout this process, organisations should prioritise elements with higher weights and focus on improving weaker areas to improve their overall PMM.

5.1 Theoretical implications

Drawing on the concepts of DCV and maturity models, this study provides theoretical insights into the realm of PM theory. First, PMC has been proposed and viewed as a significant enabler for organisation to secure sustainable competitive advantage. The main implication is that this notion may shift research focus away from the present emphasis on the size of a firm's patent portfolio and towards a capacity-based view on PM. By considering PM within the context of an organisation's age, size, or its understanding of and experience with PM, or the technical and industrial environment, the application potential of DCV becomes evident (Möhrle et al., 2018). Consequently, organisations equipped with more flexible PMCs are better positioned to sustain superior long-run performance and avoid falling into the zero-profit trap.

Second, this study aims to organise existing PM research, identify research priorities and gaps, and provide a systematic, comprehensive and adequate conceptual framework and maturity model for exploring PM activities in this evolving research area. Analysis of existing PMMMs reveals that many of them lack clear and validated procedures for evaluating maturity. While they identify key activities, they do not specify precise criteria for determining PMCs. Additionally, most models do not offer a roadmap for PM improvement, nor do they prescribe growth strategies. Almost all of the studies lack specific criteria for determining maturity levels of each element. As Wustmans et al. (2019) note in modular construction possibilities, authors intending to develop new maturity models should focus on the selection process of a specific maturity approach as well as on the decision on which elements of the approach are relevant for the organisation. The proposed model in this study integrates multiple dimensions and elements into a comprehensive framework, providing a quantitative and multi-dimensional tool for the PMM assessment.

Third, this study not only contributes to literature on how to apply the model in the domain of PM, but can also be adapted to other fields or projects in organisations involved in PMM assessment. As demonstrated in the case studies, we pinpointed the companies' strengths and weaknesses based on the assessment results, enabling us to provide practical advise and aid them in building their advancement plans and allocating resources effectively, putting the theory to the test. Additionally, this method provides a more credible benchmark to support the construction of cross-industry based PM performance evaluation.

5.2 Practical implications

The insights of the present study aim to provide practitioners valuable implications with incremental PMC improvements in an organisation, which may support an organisation in integrating, building, and reconfiguring its PM. First, the PMMM constructed in this paper may provide practitioners with a helpful tool for a focused and disciplined PM

activity by allowing decision makers to determine the action process based on the assessment results. This is due to the fact that organisations seeking to deploy PM may become perplexed by the many initiatives being performed in the name of PM. Because the model is capability-based, it allows for different elements to reach target levels while also opening up the solution space for organisation-specific practices. If all the elements are effectively developed, patents may be easily created, protected and utilised in the organisation, leading to a higher PMM.

Second, the model is useful for determining the distribution of strengths and weaknesses in different aspects of an organisation's PM. Once these managerial aspects are clarified, it might be easier to understand how and when to implement the patent activities, methods and tools to enhance PMM, which will increase the accuracy of the measurements in performing PM duties and boost the organisation's capability to make insightful decisions. An organisation with a high PMM does not always have to attain the maximum maturity level, but should strive for the maturity level which best matches the organisation's resources (Moehrle et al., 2017).

Third, moving each element up a level takes a significant amount of time and concerted effort, as well as a very clear and visible commitment on behalf of the organisation's leadership. Using this model to identify strengths and weaknesses in an organisation's current PM activity is a critical step in building consensus on the underlying PMC challenges. An organisation then sets priorities for improvement to properly allocate resources to several key dimensions and elements. When planning to achieve the desired benefits, it is critical to anticipate that certain key elements must be in place to support the achievement of higher levels of capability. In addition, obtaining higher levels of PMM necessitates a long-term commitment to continuous process improvement, which may take several years to reach the next level of maturity and reap the associated benefits (Dooley et al., 2001).

5.3 Limitations and future research

This paper has its own limitations. First, the model developed in this paper is based on a specific scenario in China and may be limited in its generalisability. Indeed, while differences in patent system between countries may have narrowed post-TRIPs, they are far from gone. For instance, there are numerous variances across countries in terms of patent coverage, duration, enforcement procedures, restrictions, and so on (David and Halbert, 2017). While every effort has been made to explore the model's adaptability in many situations, this may be challenging under certain scenarios. We may have ignored certain PMCs or failed to identify the maturity levels of certain elements properly. In addition, the use of the assignment curves to uniformly assign the five levels of maturity on a scale of 100 lacks a clear basis, given the span of scores between different maturity levels is still unknown. The final limitation is the case study's tiny sample size, which makes cross-industry comparisons difficult. Combining qualitative and quantitative research takes time, and it is difficult to collect data from a large number of organisations at different PMM levels, making the case studies difficult to uncover general distinctions across industries.

Research dedicated to assessing PMM is still its infancy stage, and there are many important issues that remain unresolved and should be addressed in future studies. First and foremost, as previously stated, the findings of this study are context-specific. To stay flexible and adaptive, the model's composition, maturity levels and weights should be

updated and adjusted in response to industry, firm size and technological development. Future research could investigate and compare PMM between organisations that rely primarily on in-house capabilities, and those that leverage outsourced forces. Furthermore, examining whether differences in PMM between companies in the same industry contribute to better innovation performance would be interesting, since the result may be particularly helpful in answering the question of what it means for firms to enhance their PMCs.

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