Review of key performance indicators for measuring innovation process performance

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Abstract: Performance indicators (PIs) are critical to the measurement of the innovation process. However, existing studies neglect PIs and dimensions relevant to companies in the current innovation landscape. This paper bridges this gap in prior research by reviewing and systematising PIs for the innovation process. It builds upon a systematic literature review to analyse scientific publications on innovation PIs published between 1983 and 2018. Thus, this study identifies the characteristics of relevant publications as well as systematises 259 PIs into nine company-specific and contextual dimensions and further categorisations. The analysis discusses the top-cited PIs and finds that more qualitative and leading PIs than quantitative exist in the literature. Furthermore, additional PIs are needed to address areas, such as leadership quality and tacit knowledge. This study may constitute an opportunity for academics to identify relevant measurement instruments and innovation managers to find an initial reference to support the selection of PIs.

Keywords: innovation process; new product development; NPD; performance measurement; performance framework; systematic literature review; SLR; performance dimensions; key performance indicators; KPIs; qualitative indicators; quantitative indicators; leading indicators.

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1 Introduction

Innovation is critical for most companies. Managers often look at successful innovative companies and wonder what they are doing right. For this, managers use performance indicators (PIs) to benchmark best practices (Becheikh et al., 2006; Richtnér et al., 2017; Brattström et al., 2018). Several of these PIs measure innovation outputs, such as the number of new products and revenue (Adams et al., 2006). Others measure innovation as patents. Some even measure input PIs, such as the number of ideas generated, whereas others focus on the balance of the innovation portfolio by examining the percentage of investments in high-risk projects vs. low risk (Crossan and Apaydin, 2010).

Nevertheless, current research fails to address recent changes in how innovation is being performed by companies (Dziallas and Blind, 2018; Frishammar et al., 2019). These changes in the innovation landscape are driven by recent performance dimensions that need to be addressed, e.g., knowledge management and innovation environment considering new trends like openness, servitisation and sustainability (Henttonen et al., 2016; Lee and Markham, 2016). Such dimensions need to be populated with relevant PIs systematised to enable companies to generate a balanced selection and avoid measuring only the inputs and outputs as opposed to the whole (Dziallas and Blind, 2018). Thus, existing studies make managers, including small and medium-sized companies, miss these changes to formulate a comprehensive view of the innovation process (Kahn et al., 2006; Lakiza et al., 2018; Sari et al., 2020).

Certainly, PIs are indispensable to the advancement of research and practice of a scientific field. For instance, in research, they can provide comparability of studies between distinct companies, industries, time-periods, cultures, and even geographic regions (Kerssens-van Drongelen and Cook, 1997; Lee and Markham, 2016). PIs also enable creating a basis for empirical validation and testing of a new theory and establishing relationships between concepts and definitions. More importantly, PIs that are reliable and valid enable the accumulation of research in a scientific field and free subsequent researchers from the need to redevelop these measurement tools (Boudreau et al., 2001; Kankanhalli and Tan, 2005).

For companies, PIs are a way for supporting managers to track organisational performance to determine the degree to which strategic objectives have been met (Dziallas and Blind, 2018). PIs can also help provide a standard framework to understand performance, support informed decisions and develop benchmarks for future comparison (Adams et al., 2006; Crossan and Apaydin, 2010). Moreover, PIs in practice can provide feedback on implementing actions, assessing implementation success, and deriving lessons learned (Dewangan and Godse, 2014).

In light of the previous motivations, this study aims to review and systematise PIs for research and practice. This goes beyond just having a metric; it requires further categorisation of the retrieved PIs to provide leading insights for researchers and practitioners (da Costa et al., 2014; Nappi and Kelly, 2018). Therefore, the resulting list of 259 PIs presented in this paper configures a comprehensive resource that consolidates dimensions and PIs from distinct studies dispersed across the literature, allowing subsequent researchers to identify more easily reliable and relevant PIs for their own research. The resulting database of PIs will also be able to support innovation managers in the selection of suitable PIs.

The remainder of this paper is organised as follows. The related theoretical background is discussed in Section 2, and the research method is presented in Section 3. Then, the paper presents the distinguishing characteristics of the identified publications in Section 4.1 and the characteristics of the identified PIs in Section 4.2. In turn, Section 5 presents the implications for managers and the contribution to the literature. Finally, the paper consolidates the conclusions, limitations and future research in Section 6.

2 Research background

The understanding and the definitions of innovation and PIs in the literature may differ; therefore, their use in this study requires further clarifications.

2.1 Innovation process

Innovation can be defined as an outcome and as a process (Crossan and Apaydin, 2010). Within the context of this research, innovation as an outcome consists of a new or significantly improved product regarding its original features or intended uses, including technical specifications, materials, software or user-friendliness (OECD, 2005). Moreover, this improved product can assume not only the form of a physical object but also a product-service system (PSS), where the material component is inseparable from the service system, enabling a lower environmental impact than the products and services offered separately (Manzini and Vezzoli, 2003; Baines et al., 2007).

Innovation as a process refers to the development and implementation of a new product. It consists of an iterative chain of activities and events, some of which are sequential while others are concurrent, aiming at delivering a successfully commercialised new idea (Cooper, 2006; Crawford and Di Benedetto, 2011). Innovation processes differ to some degree across organisations and within organisations on a project-to-project basis (Hart et al., 2003; Adams et al., 2006). The explanation relies on the innovation process's non-repetitive nature, as unpredictable events and uncontrollable external triggers may occur and influence the process (Loch and Tapper, 2002). Nevertheless, common elements from the literature can be summarised as the major components of the innovation process with the focus of disseminating best practices (Cooper, 2006; Crawford and Di Benedetto, 2011).

The innovation process can be divided into stages to illustrate these major components. The process begins with the fuzzy front-end (FFE), when idea generation, evaluation, and selection occur (Koen et al., 2001). With the ‘go’ decision of a selected idea, resources are allocated in the development stage to define, detail and test designs and/or technology (Cooper, 2006; Eling et al., 2016). As the value chain materialises into the final product, the accompanying and monitoring stage takes place until end-of-life activities are put into practice (Crawford and Di Benedetto, 2011). Despite this linear portrayal, the stages are dynamic and iterative, presenting overlaps with the company's distinct domains (e.g., procurement, operations management, supply chain), which allows several feedback loops to improve the product and the process (Cooper and Edgett, 2008).

From a small and medium enterprise (SME) perspective, the innovation process's management may display distinct characteristics than large companies. SMEs have flat structures with fewer management layers than large firms, thereby, more flexible and adaptable to changing market needs, resulting in a potential to innovate (Hudson Smith and Smith, 2007; Alegre et al., 2013). On the other hand, large companies are more likely to invest in innovation since they can allocate more considerable resources than SMEs (Kleinknecht, 1987; Becheikh et al., 2006). Moreover, SMEs may face information deficits with missing details about innovation policy and technical information due to the lack of capital (Becheikh et al., 2006).

2.2 Performance measurement

For companies, PIs are measurement tools that provide information about achieving the desired goals. In other words, they are a tracking mechanism to monitor the efficiency and/or effectiveness of actions seeking those goals (Bourne et al., 2000; Neely, 2005). Thus, they not only provide information from which one can detect problems but also encourage behaviours consistent with the company's drivers (Dziallas and Blind, 2018). PIs are often defined by title, purpose, formula, scales, and recommendations. A PI becomes a key performance indicator (KPI) when there is a rationale for understanding that what is being measured contributes directly to achieving the strategic goals (Neely et al., 2002; Niven, 2006).

This study also applies the concept of dimension. A performance dimension is understood as the broad field or category to which a PI belongs (Becheikh et al., 2006; Dziallas and Blind, 2018). They can also be acknowledged across the literature as organisational factors (Cooper and Kleinschmidt, 1995) or measured collections of practices (Markham and Lee, 2013). Dimensions are organised into typologies of PIs to help their manipulation (Adams et al., 2006; Becheikh et al., 2006; Dziallas and Blind, 2018). For example, innovation strategy is an extensively studied performance dimension (Cormican and O'Sullivan, 2004). The dimensions can also be characterised as company-specific, referring to those particular to a company or as contextual in which the dimension relates to a company and its surrounding environment (Becheikh et al., 2006; Dziallas and Blind, 2018).

Categorising PIs is becoming an established practice in research proposing the systematisation of PIs (see da Costa et al., 2014; Dziallas and Blind, 2018). Existing reviews typically apply the following categorisations: quantitative/qualitative, leading/lagging, and rapid assessment/in-depth.

- PIs can be quantitative or qualitative (Dziallas and Blind, 2018). Both types are equally important to address the innovation process (OECD, 2005).
- PIs also differ in terms of addressing the innovation process. Leading PIs are indirect determinants of process outcomes (e.g., clear innovation roles) (Rogers et al., 2005). In contrast, lagging PIs refer directly to results (e.g., new product sales) (Rogers et al., 2005). PIs may be classified as leading and lagging, for example, the number of licences in/out over the last three years (Chiesa et al., 1996). In general, leading PIs are more valuable as their use enables managers to act on the course of ongoing activities (da Costa et al., 2014).

- Relevant studies also employ rapid assessment and in-depth categorisation. Rapid assessment PIs provide a quick overview of a dimension (Chiesa et al., 1996; Czuchry and Yasin, 2001) and are easy to capture [e.g., organisational climate for innovation (Lee and Markham, 2016)]. Their application typically includes both small and large firms (Czuchry and Yasin, 2001). Conversely, in-depth PIs are resource-consuming to capture (e.g., technology synergy, a peer-reviewed PI, Atuahene-Gima, 1995). Accordingly, they are more accessible to large companies (Chiesa et al., 1996; Czuchry and Yasin, 2001).

3 Research method

This study follows a three-step systematic literature review (SLR) based on (Tranfield et al., 2003; Biolchini et al., 2005; Brereton et al., 2007). These steps are explained in further detail as follows.

The first step (planning) involves defining the keywords of the search string to gather relevant literature on innovation PIs. Papers from experts in the innovation management and new product development (NPD) fields were used to identify initial keywords, which were later refined in iterative cycles of development and tests. The resulting keywords for 'innovation process', 'performance measurement', and synonyms are presented in Figure 1 to illustrate the final search string. Web of Science (WoS) and Scopus electronic databases were selected due to their advanced web search mechanisms, high volume of indexed publications and proven relevance (Adriaanse and Rensleigh, 2013).

Figure 1 Search string

Innovation process AND	"innovation process" OR "innovation management" OR "innovation planning" OR "front end of innovation" OR "innovation front end" OR "fuzzy front end" OR ("innovation" AND ("early stages" OR "early phases")) OR "research & development" OR "research and development" OR R&D AND ("product development" OR "technology development") OR "new product development" OR "product innovation" OR "innovation design" OR "product lifecycle management" OR "product life cycle management" OR "product service system"
Performance indicators OR	"Performance measurement" OR "performance evaluation" OR "indicator" OR "metric" OR "measure" OR "index"
Additional search phrases	"Innovation audit" OR "Innovation performance" OR "Innovation front end measurement"

Note that Figure 1 contains a few keywords that are contextual to specific literature but not necessarily typical on innovation reviews. For example, 'product lifecycle management' is highly associated with the innovation process in manufacturing companies (Tolonen et al., 2015). Likewise, 'product service system' is associated with innovation in the context of product and service combined (Baines et al., 2007).

As part of this first step, researchers also specify the inclusion criteria, so the method is replicable and scientific. This study's material collection covered peer-reviewed articles indexed in either database (WoS/Scopus) to obtain a comparable research body. The search was deliberately unconstrained by groups of journal and time to encompass a broader range of journals and peer-reviewed conference papers.[1] The seven inclusion criteria are as follows:

1 available in at least one of the databases or cited in one of the identified articles

2 articles in English

3 peer-reviewed articles

4 article containing one of the keywords for PI in the title, abstract or keywords

5 articles considering the process-based view, by presenting one of the keywords for innovation process in the title, abstract, keywords or full text

6 articles specifying dimensions or categories in the full text to organise PIs

7 articles presenting a clear linkage between the innovation process success rates (sales/profit, schedule performance) and the dimensions.

Studies out of this scope were excluded from the review. The researchers further assessed the selected studies in term of quality. Five items were analysed: problem definition, research background, method, results and contributions, and insights. Thus, the papers needed to present at least a score of two to be selected, based on the scoring system: totally (1), partially (0.5) and no (0). Note that this quality ranking was an internal metric for selecting papers for this study, not reflecting any comparison amongst studies or authors.

The second step (execution) refers to the search in the electronic databases, where publications are identified and selected according to the inclusion criteria. In this review, the search fields covered management, business, planning development, economics, engineering (all kinds), operations research, computer science, multidisciplinary sciences, and social sciences mathematical methods. The articles selected were thoroughly read and assessed in terms of quality. The researchers also checked citations and references to identify additional relevant studies (cross-references) and then applied the inclusion criteria accordingly.

Further criteria are also defined to extract the PIs from the publications. Researchers followed previous criteria of SLR on PIs (see da Costa et al., 2014). PIs needed to present their title, associated with either the purpose or formula and scales. Moreover, PIs dealing exclusively with the product's technicalities, such as physical characteristics, materials, and components, were not considered. Hence, this systematic review is concerned with not only papers on PIs but also papers in which the authors measure innovation performance.

In the third step (synthesis), the relevant publications are recorded, analysed and classified. In this review, the synthesis was performed with electronic spreadsheets. The publication spreadsheet included year, source, method, industry type, and sample size. The PIs spreadsheet, in turn, presented two parts. The first included PIs' elements retrieved from the papers, e.g., title, formula/scales, purpose, units, and references. The second covered the PIs categorisation into the dimensions, leading/lagging, rapid assessment/in-depth classifications.

Researchers performed an independent two-stage evaluation to assign these classifications. In some cases, when no consensus was found, the results were discussed to arrive at an agreement. The researchers identified, catalogued and clustered dimensions to synthesise them into a higher level of categories, following the same procedure from da Costa et al. (2014) and Dziallas and Blind (2018). According to their definitions, the PIs were further categorised into the classifications (see Section 2).

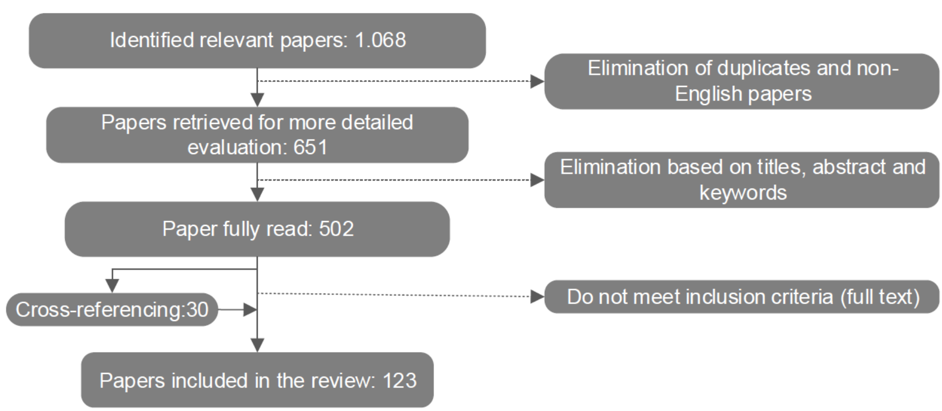
4 Results

This section presents and analyses the findings from the SLR. First, the characteristics of the selected studies are presented, followed by the results of the analysis of the PIs.

4.1 Findings from the publication analysis

Figure 2 depicts the summary of the studies' selection. By using the search criteria, 1,068 potential articles were identified, with 105 duplicates in both databases. From these, 903 articles had their main text in English. Based on the title, abstract and keywords criteria, 252 papers were excluded. Most of the excluded papers presented measurement practices, but no PIs (43%) or proposed PIs to characterise properties of new technologies or materials (22%). Moreover, several papers presented innovation PIs related to politics and policy-making (7%), supply chain (7%), human resources (7%) and civil construction (5%). Further studies were excluded for presenting the identical PIs of more recent papers of the same authorship already in the sample. One paper was withdrawn.

Figure 2 Summary of the selection of papers



Then, the introduction and conclusion of the remaining 651 were read and analysed. Less than 15% of the articles were not accessible through the electronic databases. In such cases, the authors were asked for their articles directly, and 2% were received. The full texts of the remaining 502 articles were screened in more detail. In total, 93 articles matched both the inclusion and quality criteria. Finally, additional 30 cross-referenced publications were selected by analysing citations and references of those 93 papers. In total, 123 articles were selected at the end. Within each selected paper, at least one dimension or PI was identified.

4.1.1 Publications development

Figure 3 illustrates the development of the publications per year. The number of publications between 1983–1994 is inexpressive. For 7 of the 35 years, no publication was identified from the databases. Notably, from 2004 onwards, the research focus on innovation PIs increases significantly, with a publication peak in 2018 (11). There is an overall trend that characterises an increase in publications over 1983–2018. The published articles on manufacturing sector innovation have increased since 1996, as observed in Becheikh et al. (2006) and further documented in Dziallas and Blind (2018). Accordingly, if the entire sample of 903 non-duplicated papers found by the SLR is considered, the publication growth rate is approximately 10% per year, higher than the general estimated 4.7% growth (Larsen and von Ins, 2010). In more recent years, this publication trend might originate from a series of innovation surveys, especially in Europe (e.g., OECD, 2011; EU, 2016).

Figure 3 Publication numbers per year (1983–2018)

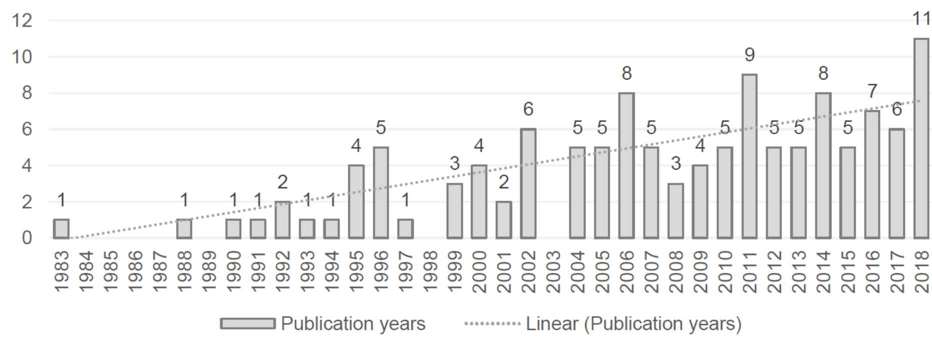


Figure 4 shows the number of papers per journal with at least two publications selected. Most papers have been published in: *Journal of Product Innovation Management* (*JPIM*), followed by the *Academy of Management Journal* (*AMJ*) and the *International Journal of Production Economics* (*IJPE*). This finding is in accordance with the journals' relevance. *JPIM* ranks 6th among the world's top journals in Engineering, with an impact factor of 4.305. *AMJ* is first in Management of Technology and Innovation Development, while *IJPE* is the 8th in Business, Management and Accounting (*Clarivate Analytics*, 2019).

4.1.2 Methods used to study innovation

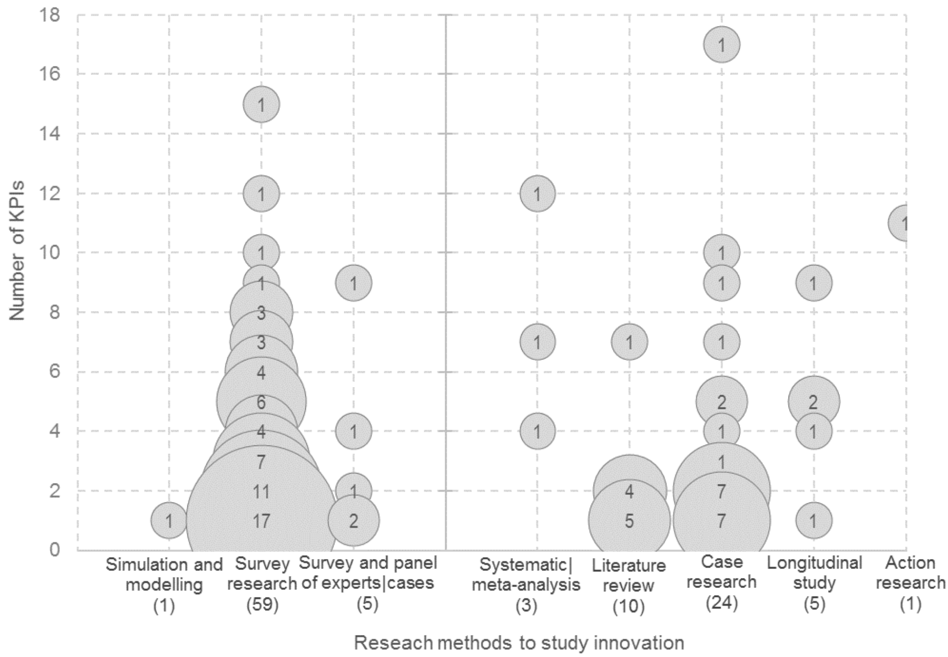
To present the methodological landscape, a comparative breakdown of the research methods is introduced in Figure 5. It illustrates a bubble plot chart in which the bubble size is proportional to the number of publications matching the pair of coordinates: number of PIs retrieved (on the vertical axis) and research method (adapted from Karlsson, 2016) (on the horizontal axis). We consider the number of PIs as a proxy for the papers' contributions, as exemplified in previous research (da Costa et al., 2014).

Figure 4 Number of publications of journals with at least two papers (1983–2018)

The research method analysis shows that among the 123 publications, most of the attention has been slightly more devoted to quantitative research methods (65 studies) rather than qualitative methods (43). Note that 15 studies among the selected publications only analyse dimensions that influence the innovation process instead of using PIs. As a result, they are not displayed in the figure.

Surveys mainly characterise the majority of the quantitative studies identified (59), either used individually or jointly with panels of experts, apart from one modelling/simulation study (Chang and Ahn, 2005). These surveys have the exploratory purpose of building theory by focusing on classifications and definitions (e.g., Cooper and Kleinschmidt, 1995). The typical data analysis techniques found were descriptive analysis and correlation analysis. In general, these studies build an increasingly better description of the phenomenon of measuring innovation performance (as in Markham and Lee, 2013).

Figure 5 Frequency of research methods and their corresponding contribution as the number of PIs (1983–2018)



Conversely, case research is the most recurrent qualitative research method (24) (e.g., Rogers et al., 2005), methodologically close to longitudinal research (5) (e.g., Driva et al., 2001). These research methods aim to test and refine theory (Karlsson, 2016), which depicts the present situation. An additional method identified was SLR with 13 examples, more inclined towards qualitative analysis (e.g., Adams et al., 2006).

In short, the identified papers discuss different methods to study innovation PIs. Future directions to be explored in the context research methods point to action research and case study to enable a deeper analysis (also pointed out by da Costa et al., 2014).

4.1.3 Publications and company size

Distinct company sizes and innovation PIs are investigated on an *ad-hoc* basis within the identified publications. Drawing on the analysis, it is possible to identify that small and medium enterprises (SMEs) are present in 29% of surveys, cases research and SLRs articles.

Surveys presented the most substantial number of studies featuring SMEs. Several publications carried out international benchmarking studies applying innovation PIs across countries (e.g., Dubiel et al., 2016; Eling et al., 2016; Markham and Lee, 2013). For example, Lee and Markham (2016) paper includes a sampling of both small and large companies in distinct geographical areas: Asia (77% SMEs and 23% large companies), North America (52% SME and 48% large companies), and Europe (59% SMEs and 41% large companies).

Case research studies also featured SMEs (40%). Tolonen et al. (2015), for instance, selected ten companies representing both large and small businesses to investigate PIs for portfolio renewal in the innovation process. In another example, Driva et al. (2001) analysed several PIs used in a small company and other PIs they intended to implement in their measurement system.

Lastly, SLRs occasionally addressed small companies' issues. 23% of the studies mentioned issues related to SMEs. For instance, Adams et al. (2006) discussed PIs not suited for small companies (e.g., research and development – R&D intensity). Additional reviews, such as Becheikh et al. (2006) and Dziallas and Blind (2018), briefly discussed shortcomings faced by SMEs in collecting PIs data, e.g., deficits of information.

4.1.4 Publications at the industry level

The industry analysis of the selected literature is based on the International Standard Industrial Classification of all Economic Activities (ISIC) classification (United Nations, 2008). The manufacturing industry accounts for 81% of the selected articles. The manufacturing industry's meaningful participation is most likely due to the attention given to performance measurement research in the operations management field, which evolved from the total quality management movement.

Additional publications correspond to scientific R&D for further application into the machinery, electronics and automobile industry, representing 9% of the sample. Finally, the remaining studies are situated in the service sector (9%). This observation demonstrates an emerging shift in the research efforts from manufacturing to the service industry. This change may have resulted from specific trends, e.g., communication and information technology and software industry grow (Dziallas and Blind, 2018), as well as extended focus on services into product offers for customers (Baines and Lightfoot, 2013). Articles that did not describe a specific industry branch were excluded from this analysis (approximately 1%).

4.2 Synthesis of the literature

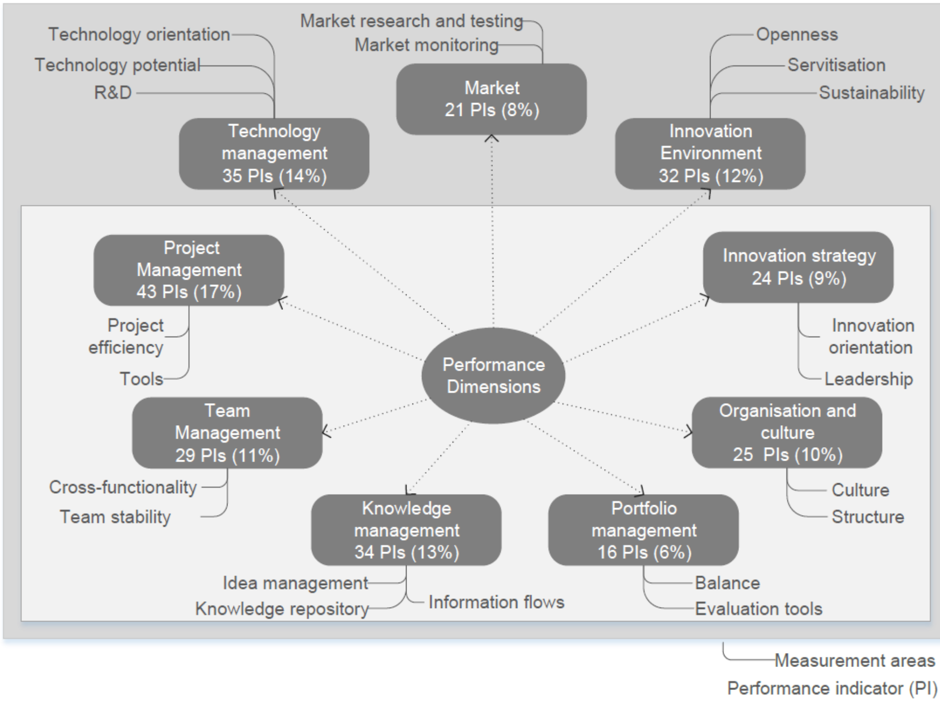
Following the research method, the SLR allowed the identification of performance dimensions and relevant PIs, as discussed next.

4.2.1 Performance dimensions

To classify the broad range of PIs, a framework was setup based on the identification, registration, and clustering of performance dimensions. The framework showing the refined dimensions as well as their measurement areas is illustrated in Figure 6, which is complemented by the numbers of PIs classified within each dimension. As mentioned previously, these dimensions determine the innovation process and the resulting new product.

In total, nine dimensions are determined. The identified dimensions had to be present across three main literature bodies: performance frameworks (Adams et al., 2006; Becheikh et al., 2006; Crossan and Apaydin, 2010; Dziallas and Blind, 2018), measurement of organisational factors (Cooper and Kleinschmidt, 1995; Chiesa et al., 1996; Verhaeghe and Kfir, 2002; Rogers et al., 2005); and, measurement of collection of practices (Panizzolo et al., 2010; Barczak and Kahn, 2012; Markham and Lee, 2013; Akroush and Awwad, 2018).

Figure 6 Dimensions and measurement areas for synthesising PIs (1983–2018)



As multiple internal and external elements affect companies' ability to perform the innovation process, the dimensions are divided into company-specific and contextual dimensions (Becheikh et al., 2006; Dziallas and Blind, 2018). First, company-specific dimensions include those particular to a company, affecting its internal organisational capacity. The company-specific dimensions and their *measurement areas* are as follows:

- *Innovation strategy:* Relates to the coordination of a company's innovation efforts in its units, divisions, or individual projects to achieve long-term innovation goals. It is built upon on company's *strategic orientation* and *leadership* measurement areas to establish aligned and coordinated innovation efforts (Adams et al., 2006; Crossan and Apaydin, 2010). This dimension represents 9% of all PIs.
- *Knowledge management:* Comprises *idea management*, gathering of information to enrich and inform decisions concerning those ideas (*information flows*), and maintenance of a *knowledge repository* to support management (Verhaeghe and Kfir, 2002; Rogers et al., 2005; Crossan and Apaydin, 2010; Markham and Lee, 2013). The dimension represents 13% of all PIs.
- *Organisation and culture:* Refers to the *organisational structure* that regulates how rules, hierarchies, and responsibilities are coordinated among staff involved in the innovation process, and the *culture* denotes the beliefs and values system within which they work (Adams et al., 2006; Dziallas and Blind, 2018). In total, this dimension scores 10% of the identified PIs.

- *Portfolio management:* Embraces the selection of projects ideas with *evaluation tools* to achieve a strategical fit between the available resources and the company goals and drivers and reach a *balance* of the innovation projects in the company's portfolio (Adams et al., 2006; Crossan and Apaydin, 2010; Barczak and Kahn, 2012; Markham and Lee, 2013). At only 6%, this is the least developed dimension.

- *Project management:* Deals with the application of *project management tools* to support the conduction of new projects, with coordination amongst departments and functions, which in turn enables the achievement of the established project's requirements with *efficiency* (Chiesa et al., 1996; Verhaeghe and Kfir, 2002). This dimension is the most frequent, accounting for 17% of all PIs.

- *Team management:* Management of teams is considered an essential dimension for the management and improvement of innovation performance. It is built upon two critical measurement areas: *cross-functionality* of teams (also called multidisciplinary) and team *stability* (Cooper and Kleinschmidt, 1995; Verhaeghe and Kfir, 2002). This dimension represents 11% of all PIs.

Contextual dimensions, in turn, are related to the company's surrounding environment, meaning that external elements have a greater influence in this type of dimension (Becheikh et al., 2006; Dziallas and Blind, 2018):

- *Innovation environment:* As companies are adaptive systems that adjust to the surrounding environment, they need to react to current external forces to improve innovation performance. These forces relate to *openness* to enable external collaborations, *sustainability* and *servitisation* of physical products (Panizzolo et al., 2010; Lee and Markham, 2016). This dimension corresponds to 12% of the PIs.

- *Technology management:* Encompasses the *technology orientation* of the company's activities as well as the anticipation of the *potential of new technologies* to propose programs for developing competencies and enable *R&D efficiency* (if it applies to the company) (Chiesa et al., 1996; Verhaeghe and Kfir, 2002; Markham and Lee, 2013). As shown in Figure 6, this dimension represents 14% of all PIs.

- *Market:* Includes *market research and testing* of the new product/PSS concepts during development in addition to *monitoring the market* during distribution, delivery and use, that includes issues such as material disposal and other end-of-life strategies (Crossan and Apaydin, 2010; Panizzolo et al., 2010). The market dimension constitutes 8% of all PIs.

From our review, we can see that Crossan and Apaydin (2010) present several dimensions in common with this study, such as innovation strategy, knowledge management, culture, project management and market. Even though their framework is the one with most dimensions from the literature (seven), they do not provide a complete overview dimension-wise. Interestingly, Richtnér et al. (2017) already identified in the literature the need to include PIs addressing the innovation environment, namely, openness and servitisation. Thus, this presentation of the nine dimensions provides a more comprehensive take on the innovation process than existing studies. These dimensions may also overlap with the company's distinct disciplines (e.g., strategic planning, quality control, supply chain) situated beyond the innovation process's frontiers. In this way, these dimensions are key to managing and improving the innovation process as well as other domains (Adams et al., 2006).

4.2.2 Performance indicators

In total, 259 PIs were identified and catalogued according to the inclusion criteria explicitly designed for the indicator's identification. Table 1 shows the top-cited PIs according to their dimensions and measurement areas identified in the literature. The table also displays their classifications, that is, whether the PIs are rapid assessment (also applied in SMEs) or in-depth, qualitative or quantitative, and leading, lagging or potentially both. The top-cited PIs were determined by the Pareto rule (80/20) applied to the number of citations. Meanwhile, the full list of 259 PIs because of its considerable size is available in the following link: (https://osf.io/q2we9/?view_only=34d767f29f9d430b8a54a29f25f41150).

The 259 PIs are collectively exhaustive and representative of the literature identified via the SLR. Beginning with the innovation strategy dimension, the PI most commonly cited is the 'percentage of employees aware of, sharing the innovation goal, policies and values' (Cooper and Kleinschmidt, 1995; Chiesa et al., 1996). Evidence shows that this rapid assessment PI was applied in SMEs and large companies (e.g., Cooper and Kleinschmidt, 1995). It provides insights into the role of innovation leadership in disseminating innovation strategy. Thus, this PI can help managers focus on key actions to increase awareness and clarity of innovation efforts that could contribute to corporate goals. For large companies, this PI can be complemented with the 'role of NPD program clear to all' to deal with innovation leadership and 'corporate goals for NPD program' to evaluate innovation strategic orientation (Cooper and Kleinschmidt, 1995).

Several PIs are available for idea management in the knowledge management dimension (Chiesa et al., 1996). However, the 'percentage of ideas generated in formal vs. informal activities' is the PI indicated to analyse the extent to which firms are using different generative tools (e.g., brainstorming, competitor analysis) (Adams et al., 2006; Lee and Markham, 2016). As formal idea generation leads to higher success rates (Eling et al., 2016), this PI encourages formal activities for SMEs and large firms (Markham and Lee, 2013). Besides, it is often used with the 'percentage of innovative ideas reviewed' (Adams et al., 2006). Another highly cited PI since (Kleinknecht, 1987) is 'patents filed'. However, the patent-related PIs are limited, as not all innovations are patented (Adams et al., 2006; Crossan and Apaydin, 2010). An alternative may be external recognition (e.g., 'external awards' Tipping et al., 1995).

A leading PI of the culture and organisation dimension is the 'organisational climate for innovation' (Markham and Lee, 2013). This PI has application in both SMEs and large companies. It enables managers to see how the company faces the understanding of failure in the FFE, for instance (Markham and Lee, 2013). 'Support for experimentation' PI can also improve the understanding of a company's beliefs and values towards experimentation (Cormican and O'Sullivan, 2004). A complementary leading PI consists of a 'work environment for innovation' that addresses the organisational structure by indicating the resources available for creativity and the incentives (Prajogo and Ahmed, 2006).

Table 1 Top cited PIs from the literature (1983–2018)

Dimension	Measurement areas	PI title	Citations	Classifications					
				R	*In*	L_1	L_2	Q_1	Q_2
Innovation strategy	Innovation orientation	Product strategy plan	3		x	x	x		x
		Corporate goals for NPD (new product development) program	5		x	x	x		x
		Product planning horizon (years, product generations)	3	x		x			x
		Role of NPD program clear to all	3		x	x			x
	Innovation leadership	Commitment to differentiated funding sources	3		x	x	x		x
		Percentage of employees aware of, sharing the innovation goal, policies and values	7	x		x		x	
Knowledge management	Idea management	Percentage of ideas generated in formal/informal activities	7	x		x		x	
		Percentage of innovative ideas reviewed	3	x		x	x	x	
	Knowledge repository and implementation	Number of patents filed	8		x	x		x	
		Rate of R&D projects that lead to new or enhanced products, process innovations, licences, patents	3		x	x		x	
	Information flow	Rate of team leaders trained in creativity techniques	3		x	x		x	
		Extent of usage of distinct idea generation sources	3		x	x		x	
Organisation and culture	Culture	Organisational climate for innovation	3	x		x			x
		Support for experimentation	3		x	x			x
		Degree of accommodation of failure	3		x	x		x	
	Organisational structure	Work environment for innovation	3	x		x			x
		Organisational structures for conducting innovation projects	3		x	x			x
Portfolio management	Balance	Portfolio alignment	4	x		x			x
		Portfolio balance	3	x		x		x	
		Portfolio size	3		x	x		x	
	Evaluation tools	Portfolio mindset of the portfolio decision making effectiveness	3		x	x			x
		Existence of a formal portfolio management	3	x		x		x	
		Agility of the portfolio decision making	3		x	x			x
Project management	Project efficiency	Project costs/duration (budget vs. actual)	8		x	x		x	
		Project execution success	4		x		x		x
		Innovation project speed per stage	3	x		x		x	

Notes: With their classifications: Rapid assessment (R) and in-depth (In), leading (L_1) and lagging (L_2), and quantitative (Q_1) and qualitative (Q_2).

Table 1 Top cited PIs from the literature (1983–2018) (continued)

Dimension	*Measurement areas*	*PI title*	*Citations*	*Classifications*					
				R	*In*	L_1	L_2	Q_1	Q_2
Project management	Project efficiency	Technical performance success	3		x		x		x
	Tools	Frequency of projects post review (percentage or number)	3	x		x		x	
		Project complexity	3		x	x			x
Technology management	Technology orientation	Level of monitoring new technologies	3	x		x			x
		Constantly thinking of new technology	3		x	x			x
		Degree technology tools used	3	x		x		x	
	Technology potential	Mix of technology internal development vs. technology transfer	3		x	x		x	
		Technology novelty	3		x	x			x
	R&D	R&D intensity	3		x		x	x	
Team management	Cross-functionality	Frequency of cross-functional training	4	x		x		x	
		Level of cross-functionality in teams	3	x		x			x
		Team ability for multi-skilling	3		x	x			x
	Team stability	Dedicated project group assigned to the innovation task	3	x		x			x
		Identifiable team leader	3	x		x			x
		Team potency	3		x	x			x
Market	Market research and testing	Use of market research tools	3	x	x	x		x	
		Importance given to market analysis, planning and monitoring	3		x	x			x
		Percentage of time of reaching the customer	3		x	x		x	
	Market monitoring	Aftersales personnel proficiency	5		x	x			x
		Product launch proficiency	3	x		x	x		x
		Commercialisation schedule adherence	3		x	x			x
Innovation environment	Openness	Percentage of third parties/partners with collaborative projects	4		x	x	x	x	
		Recognition of key problems that must be solved with skills that reside outside the organisation	3	x		x		x	
	Servitisation	New product diversification strategy	3		x	x		x	
		Proficiency in service design	3		x	x			x
	Sustainability	Utilisation of sustainability criteria for new product	3		x	x			x
		Internal development of sustainability policies	3		x	x			x

Notes: With their classifications: Rapid assessment (R) and in-depth (In), leading (L_1) and lagging (L_2), and quantitative (Q_1) and qualitative (Q_2).

A predominant PI for portfolio management is the 'balance in the selection of new projects between long vs. short-term, high vs. low risk' across markets and technologies (Killen et al., 2008). This leading PI is particularly useful for large companies. Additional leading PIs are portfolio alignment and size (Killen et al., 2008). A further helpful PI is the 'agility of the portfolio decision-making' to address evaluation tools' proficiency (Kester et al., 2014).

For project management, the 'frequency of post-project review' is a vital PI for indicating the company's learning practices (Atuahene-Gima, 1995; Cooper et al., 2004). This leading PI, already in use in SMEs and large companies, builds accountability for the project end-results and enables lessons learned for future reference (Cooper et al., 2004; Lee and Markham, 2016). Furthermore, a highly mentioned leading PI is based on 'comparisons between planned and actual project parameters' (costs, duration) addressing the project management efficiency (Rogers et al., 2005).

Examples of team management PIs are the 'level of cross-functionality' (Cooper et al., 2004) and 'frequency of cross-functional training' (Chiesa et al., 1996). Cross-functionality is a well-researched area, even for SMEs with fewer layers, where each team member should also present complementary competencies (Cooper et al., 2004; Dayan and Di Benedetto, 2009). These leading PIs can also enable the visualisation of the integration of the commercial and technical role, critical during the decision-making process (Dayan and Di Benedetto, 2009). Likewise, an 'identifiable team leader' is a vital PI in terms of team stability (Lee and Markham, 2016).

'R&D intensity' is a lagging PI for the technology management (Ebersberger and Herstad, 2011), expressed as the ratio between R&D expenditures or professionals and total (Kivimäki et al., 2000; Parthasarthy and Hammond, 2002). It is designated for large companies as SMEs may not have formal R&D nor dedicated personnel (Kleinknecht, 1987). Conversely, relevant PIs, for SMEs and large, can be the 'level of monitoring new technologies' and 'mix of internal technology development vs. technology transfer'. Both can be used as signposts in the search for external triggers referring to technology orientation (Lee and Markham, 2016).

'Product launch proficiency' represents a top-cited PI for the market dimension (Song and Parry, 1996). The employment of such a lagging PI for both small and large companies can address the adequacy of distribution and promotional support (Adams et al., 2006). A further example of a market PI is the 'use of market research tools' to provide performance information on market research and testing (Atuahene-Gima, 1995).

For the innovation environment dimension, examples of openness PIs are the most frequent, e.g., the 'percentage of collaborations with third parties' (Dubiel et al., 2016). The most recurrent PI for sustainability, in turn, articulates the 'utilisation rate of sustainability criteria for new products' (Markham and Lee, 2013). Finally, the top-cited servitisation PI is the 'new product diversification strategy' expressed by the budget spent on products, services, and mix (Lee and Markham, 2016). These three examples have been used in SMEs and large organisations alike (Markham and Lee, 2013).

Furthermore, the findings, in general, reveal more qualitative (131) than quantitative (95) PIs (see Table 2), consistent with observations from prior research (Dziallas and Blind, 2018). One explanation is that the retrieved PIs refer to both non-technological and technological innovations. Additionally, lagging (31) and leading/lagging PIs (25) are less frequent than leading (203), as more intangible and in-between dimensions, such as organisation and culture and knowledge management, are more frequent now. Further results also show that most PIs are applied in large companies (225 in-depth) rather than small firms (34 rapid assessment). This observation resonates with the percentage (29%) of relevant studies addressing SMEs (see Section 4.1.3).

Table 2 Overview of the classifications of the PIs (1983–2018)

	Rapid assessment	*In-depth*	*Leading*	*Lagging*	*Leading/lagging*	*Total*
Quantitative	17	77	65	15	14	95
Qualitative	17	114	109	12	10	131
No formula		34	29	4	1	34
Total	34	225	203	31	25	259

From our literature review, we can also specify gaps identified that have not been fulfilled yet, as illustrated in Table 3. The first relates to the lack of PIs for leadership quality in the innovation strategy (Adams et al., 2006). Throughout the innovation process, tacit knowledge is also a gap, as indicated by Wang et al. (2010). There is relatively little on PIs for measuring organisational flexibility and responsiveness to change in the organisation and culture dimension (Bititci et al., 2012) and portfolio balance concerning incremental vs. radical innovation (Killen et al., 2008). Besides, several PIs within project and technology management still have a techno-centric bias, evidencing that more studies are needed to address non-technological innovations (Dziallas and Blind, 2018). Moreover, team elements such as synergy and team autonomy need to be further investigated (Akroush and Awwad, 2018). Finally, there is an absence of PIs to address service sectors, especially in the market and innovation environment dimensions (Markham and Lee, 2013).

Table 3 Literature gaps for future research on PIs

Performance dimension	*Measurement gaps*
Innovation strategy	Leadership quality
Knowledge management	Tacit knowledge
Organisation and culture	Organisational flexibility and responsiveness to change
Portfolio management	Incremental/radical portfolio balance
Project management	Non-technological innovations
Technology management	Non-technological innovations
Team management	Synergy, team autonomy
Market	Service industry
Innovation environment	Product-service system (PSS), open innovation

5 Discussion and implications

The main drive for undertaking this research is that a clear and relevant systematisation of PIs can help not only researchers identify what the literature can offer to support further research (Becheikh et al., 2006) but also innovation managers to evaluate innovation performance (Adams et al., 2006; Dziallas and Blind, 2018).

The identification of nine dimensions can be beneficial for managers who may need help with the definition of relevant performance dimensions to consider in the company as well as know more about recent trends in the innovation landscape, e.g., innovation environment with openness, servitisation and sustainability. Additionally, the identification of relevant dimensions and further systematised PIs can present benefits for researchers too. PIs that are reliable and valid enable the accumulation of research in a scientific field and free further researchers from redeveloping them. For instance, although other studies address dimensions, the most extensive study presented only seven. This study can also contribute to the literature with indications for future research, such as applying action research and case study or including SMEs or service industry in the research design.

The results also provide the top-cited PIs. An implication for innovation managers entails to use them as an initial reference in the selection of KPIs. These PIs are a proxy of a priority ranking to support the selection of PIs. This would provide more free time for innovation managers to pursue further measurement activities. Currently, three companies are applying the PIs systematised in this research.[2] Additionally, another implication resides in the identification of a higher number of in-depth PIs (225). This observation resonates with previous research that demonstrates that most PIs were designed for large companies (Hudson Smith and Smith, 2007; Nappi and Kelly, 2018). SMEs sometimes face the challenge of information deficits so, Hudson Smith and Smith (2007) point out considerable difficulties in implementing in-depth PIs.

Further results indicate that most PIs identified are leading PIs. The possible reason is that output-oriented PIs for more intangible dimensions, for example, organisation and culture and knowledge management, are challenging to capture. Combined with that, authors in the related literature have also recognised a higher research value if they focus on leading PIs since they are easier to be acted upon and, then, influence the innovation process results (da Costa et al., 2014). Thus, innovation managers should prioritise the use of leading PIs since this type enables them to act during the innovation process, avoiding the need to wait for the innovation outcomes at the end of the innovation process cycles.

Finally, the efficacy of using these PIs in practice depends on the competence of the management in applying them. Although the study aims to provide systematic and comprehensive PIs, several subjective judgments are necessary for using those, including determining which strategic goals are important and which PIs need to be given higher weight.

The present study helps identify the metrics that should be given greater importance by functioning as a checklist, facilitating the selection of PIs that are most likely to be KPIs because of their leading and rapid assessment features. Thus, PIs systematised here can be used as a source of information to innovation managers. This database of PIs can also become a reliable source of PIs that could free subsequent researchers from the need to redevelop these measurement instruments and avoid reinventing the wheel all over again.

6 Conclusions

Companies are increasingly studying their innovation processes to become more innovative. Measuring innovation performance is key to these efforts (Adams, Bessant and Phelps, 2006; Crossan and Apaydin, 2010; Dziallas and Blind, 2018). Within this context, PIs are management tools that enable managers to measure innovation performance.

The paper highlights the importance of the PIs systematisation for practice. It identifies nine performance dimensions from the literature, including company-specific and contextual dimensions. The breadth of these dimensions can be used as a reference for managers, as they can identify areas of the innovation process where attention and resources should be focused. Thus, our systematisation allows managers, including SMEs, to have a comprehensive view of nine dimensions that address the current innovation landscape as well as to access 259 state-of-art PIs. Furthermore, this systematisation can also enable the dissemination of a common language and a shared vision across the company and help managers avoid the typical mistake of measuring only the inputs and outputs of the innovation process as opposed to the whole.

This study also has theoretical implications. With the literature review, it was possible to provide a systematisation of dimensions and PIs, from which researchers can evaluate the applicability to other contexts. A compilation of such magnitude in terms of PIs and dimensions enables the update and accumulation of research in a scientific field and free researchers from redeveloping them. Certainly, the number of PIs dimensions indicates a more comprehensive view of the process than existing research. A further contribution to the literature concerns the indication that future research could apply action research and case study or focus on SMEs or the service industry.

This study is not without limitation. As the identification of publications is based on the string search, other articles might not have been included despite the extensive range of papers identified. Also, several PIs were seldom vaguely, so the systematisation relied on surrounding definitions as provided by the respective authors. Moreover, the researchers performed the leading and lagging and quantitative evaluations of the PIs, as previous research (da Costa et al., 2014; Dziallas and Blind, 2018). The results may be subjective rather than objective despite the proficiency of the researchers. Therefore, further study is required to generalise the results.

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Abbreviations

FFE	Fuzzy front-end
KPI	Key performance indicator
NPD	New product development
PI	Performance indicator
R&D	Research and development
SLR	Systematic literature review
SME	Small and medium enterprise

Notes

1 Recent systematic reviews on innovation management recommend an extended timeframe to reach more relevant results and not constrained to ten years of publications (e.g., Dziallas and Blind, 2018).

2 Unfortunately, their use is out of the scope of this research and protected with a non-disclosure agreement.