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Highlights

- We provide a unified taxonomy for KPIs management that gathers any relevant aspect highlighted by the literature.
- We rigorously apply a methodology for taxonomy development in the Information Systems field.
- The taxonomy defines a five-based dimension comparison including around 21 different aspects.
- We provide the reader with a complete and consistent background of KPIs-based concepts.
- We provide a comprehensive comparison of the proposed taxonomy with other similar works.

A Taxonomy for Key Performance Indicators Management

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Abstract

In recent years, research on Key Performance Indicators (KPIs) management has grown exponentially, giving rise to a multitude of heterogeneous approaches addressing any aspect concerning it. In this paper, we plot the landscape of published works related with KPIs management, organizing and synthesizing them by means of a unified taxonomy that encompasses the aspects considered by other proposals, and it captures the overall characteristics of KPIs. Since most of the literature centers on the definition of KPIs, we mainly focus on such an aspect of KPIs management. Our work is intended to provide remarkable benefits such as enhancing the understanding of KPIs management, or helping users decide about the most suitable solution for their requirements.

Keywords: KPIs, Performance measurement, Taxonomy

1. Introduction

Enterprises and institutions need to evaluate their activity in order to determine the extent to which their goals have been achieved. One possible way to carry out this evaluation is to measure performance, for which organizations rely on metrics known as Key Performance Indicators (KPI). *KPIs represent a*

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set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization [1].

KPIs play an important role in turning organizational goals to reality [2], helping organizations to understand how well they are performing in relation to their strategic goals [3]. More specifically, (1) KPIs can give organizations reliable information to establish the basis for implementing their growth strategies, (2) performance indicators provide a way to see whether the followed strategic plan is working, serving as tools to drive desired behavior, and (3) their use can particularly increase and improve operational efficiency, productivity and profitability. Considering these potential benefits, it is no wonder that all aspects involved around KPIs are consequently of paramount and increasing importance. In particular, the growing interest in this topic is evidenced by its use in a wide number of fields within the business environment such as public transport system [4], product service system [5], or supply chain network [6].

Thus, having an effective, relevant KPI selection has become essential and increasingly critical in today's competitive business environment [2]. Defining KPIs constitutes a cumbersome task since it includes a broad number of aspects such as business strategy, business objectives, KPI modeling, measurement, analysis and reporting [7]. For this reason, companies normally rely on managers and staff to choose and monitor the suitable KPIs.

1.1. Motivation

Considering the above situation, it is natural that in recent years there has been a rapid growth of the research devoted to the KPI field, which particularly has derived into a large and heterogeneous research corpus of approaches to address any aspect concerning it. Even so, at the present time there appears to be no clear consensus or common ground on aspects such as what requirements a KPI should support, what elements are involved in formalizing the concept of a performance indicator, or what relations to other formalized concepts such as goals, processes and roles are needed [2].

Although these existing works provide research aspects in matters as varied as modeling, evolution or expressiveness of KPIs, they usually tackle such issues from different perspectives, even using different terminology to refer to the same concept. And not only that, as we will see later, there has been few effort towards the definition of a structured knowledge organization of KPIs. As stated in [8], the absence of a common terminology and an organized structure of knowledge items can be an obstacle to the communication and understanding of the produced research–related information, making works harder to analyze and compare, or even find interrelationships among such works. This issue can be an impediment to both the progress in research and the transfer of research results to the market. In this context, classification schemes can contribute to mitigate the aforementioned problems [8].

Taking this into account, and given the size and heterogeneity of the literature, we have seen the need to organize and synthesize the existent research corpus, by means of establishing a taxonomy for KPIs management. In this context, we refer to *KPIs management* as any aspect involved around the KPI field ranging from KPIs' design and specification, through maintenance, evolution and tool support, to the control of KPIs' related roles and responsibilities. From now on, in this paper, we simply refer to our taxonomy as "taxonomy for KPIs management".

Taxonomies have long been important tools for organizing information. Nowadays, many organizations build taxonomies as part of their information management strategies [9], being several the proposals which use taxonomies as classification structures to organize the knowledge within a specific field (for example, in education [10], chemistry [11], or in computer science [12, 13]). There are interesting benefits that a classification scheme, and specifically a taxonomy, can provide to both researchers and practitioners [8, 14, 15], such as (1) providing a set of unifying constructs that characterize the area of research, easing the share of knowledge, (2) giving better ways of understanding the interrelationships among the different aspects associated to a particular knowledge area, (3) helping to identify knowledge gaps, and (4) contributing to give support to decision making processes.

1.2. Contribution

The contributions of this paper are based on a comprehensive overview covering both early and recent works that have tackled any issue regarding KPIs management. As a result, we provide a taxonomy which, in a unified way, gathers together any relevant aspect highlighted by the literature and which captures the unique characteristics of KPIs in a more fully way. More specifically, this taxonomy identifies different issues of interest distributed along several key dimensions. We note that, since most of the literature centers on KPIs definition, our taxonomy focus mainly on such an aspect of KPIs management.

Our work is thus intended to provide several benefits. First, our taxonomy and review of related background aim at informing and enhancing the understanding of the field to potential researchers, practitioners or KPIs' users. Second, the results provided by this work could be particularly relevant for potential researchers aimed at identifying research issues regarding either the definition of KPIs that have been already tackled or directions for future research. Last but not least, since users' needs can be extremely varied, our taxonomy enables such an audience to distinguish between different perspectives of KPIs management, and guide them in their decision towards the specification of concrete KPIs. Therefore, the selection of the most suitable solution for their requirements is facilitated.

The paper is structured as follows: Section 2 describes the method we have followed to develop our taxonomy. In Section 3 we present the taxonomy for KPIs management. Section 4 discusses the evaluation of the taxonomy under different criteria. Finally, Section 5 covers the main conclusions of the paper.

2. Methodology

We have derived our taxonomy by applying the method for taxonomy development proposed by Nickerson et al. [16]. This method proposes, as first step, to determine the meta–characteristics that will serve as the basis for the choice of the characteristics in the taxonomy. In order to do this, the potential users of the taxonomy and its purpose must be identified. In our case, the users of the taxonomy are researchers, practitioners and KPI's users, and the purpose is to provide them with a structured set of issues concerning KPIs management. Thus, we set the meta-characteristics as *any aspect (i) concerning the overall KPIs' management life cycle or (ii) related to the purposes for which KPIs may be used (intention).*

Since in [16] authors propose an iterative development method, the second step is devoted to determine the objective and subjective conditions that end the process. In our particular case, we adopted the eight additional *objective* conditions identified in [16, pp. 344] which, in our case, would include aspects such as (1) that at least one KPIs management element is classified under every characteristic of every dimension, (2) that no new dimensions or characteristics was added, merged or split in the last iteration, or (3) that every dimension is unique and not repeated. As *subjective* ending conditions, we adopted the conditions of [16]: *concise*, *robust*, *comprehensive*, *extendible*, and *explanatory* (see Subsection 4.1).

Regarding the iterative process, the method distinguishes two approaches: *inductive* or *empirical-to-conceptual*, which is appropriate when the researchers have little understanding of the domain but significant data about the objects is available, and *deductive* or *conceptual-to-empirical*, which is advised if little data are available but the researchers have significant understanding of the domain. In our particular case, we have access to both, extensive data (a huge number of KPIs management proposals in the literature) and considerable knowledge of the domain (own experience). Thus, we chose to follow an *inductive* approach to identify key aspects involved around KPIs management as considered by existing proposals, and later to conceptualize dimensions and characteristics of such aspects of interest.

On the *empirical* side, as indicated by [16], we performed a review of the literature to identify published KPIs management proposals, so that we can base on a wide number of objects to be classified by our taxonomy. More specifically, we performed a structured literature review based on original guidelines described in [17, 18], including research studies published from January 2008 to September 2018. In order to make sure that the studies included in the review were clearly related to the research topic, we defined detailed general guidelines for inclusion and exclusion criteria. More specifically, the scope of the review was limited to the literature that establishes any kind of ontology/metamodel/taxonomy or categorization tackling any issue involved around KPIs management such as: (i) any aspect concerning the overall KPIs management life cycle, or (ii) any aspect related to the purposes for which KPIs may be used. In contrast to other proposals, we did not limit the search to a specific domain of application. On the other hand, we excluded pure discussion, opinion papers or tutorials. We also excluded any study reported in a language other than English. As electronic databases, we considered Scopus and Science Direct since they offer good coverage, reputation, advanced features to perform the search and exportability (specially as BibTeX format). As keywords and search terms, in order to be as unbiased as possible, we chose a set of general search terms classified into two different groups, including associated terms and synonyms: *KPI concepts* (performance indicator, performance measure, performance measurement, performance metric) and *classification concepts* (ontology, metamodel, taxonomy, categorization, categorizing). The automatic electronic search was performed using the advanced search of each data source, looking for all possible permutations of the established *KPI* and *classification concepts*, in *titles*, *abstracts*, and *keywords*. This first search resulted in 912 papers identified (considering also duplicates). After this stage: (1) we ruled out of duplicates and excluded studies with titles clearly not related to the research focus (786 papers identified), (2) we excluded studies on the basis of *titles*, *abstracts* and *keywords* (106 papers identified), and (3) we scanned the candidate papers and also undertook a process of snowballing, paying special attention to “Related Work” sections. Finally, we selected 46 papers.

On the *conceptual* side, inspired by the taxonomy proposed in [12], we decided to identify our dimensions following a question–based strategy. More specifically, we have set out several questions tackling different aspects concerning KPIs management, each question constituting a different dimension (see next section).

At the end of the process, the stated *objective* and *subjective* criteria served as ending conditions for the development process. We can identify several threats to validity of the overall process. First, whether we have identified adequate keywords and chosen suitable engines during the review. On this count, the ample list of different papers indicates that the width of the search is sufficient. Second, another possible threat to validity corresponds to bias in applying quality assessment and data extraction. In order to minimize this threat insofar as possible, we explicitly established the inclusion and exclusion criteria, which we believe were detailed enough to provide an assessment of how we selected the chosen papers for the analysis. Finally, we have used the *subjective* criteria as evaluation criteria for the resulting taxonomy (described in Subsection 4.1). In order to test the validity of our taxonomy, we have compared it with other proposals (see Subsection 4.2), and we have applied the proposed taxonomy to a real context by using real examples (see Subsection 4.3).

3. Our Proposed Taxonomy

After following the methodology for taxonomy development, we get a comprehensive taxonomy which encompasses the overall aspects considered by other proposals, and which more fully captures the unique characteristics of KPIs management (focusing mainly on KPIs definition). The resulted taxonomy establishes five dimensions regarding KPIs management, attempting to answer:

- *What is measured by a KPI?*, which aims at clarifying the different aspects to be measured by KPIs.
- *What features are considered in the specification of KPIs?*, which addresses the several and varied features that can be considered in the specification of KPIs.

Table 1: Meta-characteristics and associated dimensions

Meta–characteristic	Question–based dimensions
Aspects concerning the overall KPIs' management life cycle	What is measured by a KPI?
	What features are considered in the specification of KPIs?
	What artifacts are used for KPI design and specification?
	What are the characteristics of a KPI management approach?
Aspects related to the purposes for which KPIs may be used (intention)	What is a KPI measured for?

- *What is a KPI measured for?*, whose intention is to identify the different purposes for which a KPI may be used.
- *What artifacts are used for KPI design and specification?*, which aims at clarifying the types of elements commonly used to create KPIs.
- *What are the characteristics of a KPI management approach?*, which addresses the different particularities to manage KPIs used by existing proposals.

At this point, we want to highlight the relationships among the meta–characteristics we have previously identified, and the dimensions in our taxonomy (see Table 1). More specifically, the dimensions related to the first, second, fourth and fifth questions, are derived from the first group of aspects identified in the meta-characteristic, while the dimension concerning the third question is a logical consequence of the second group of aspects identified in the meta-characteristic. Additionally, for each dimension, we have identified several categories which correspond to concrete aspects to focus on when tackling a specific question. So that the reader can get an overall view of the taxonomy itself, in Figure 1 we depict the dimensions together with only their upper level aspects. For example, regarding the question *What is measured by a KPI?* in Figure 1, we can distinguish among the *Performance measurement perspectives*, *Rationale* and *Scope* aspects. More specifically, for each question/dimension and its concrete aspects, we have identified a wide number of terms and concepts commonly used by the analyzed works. Taking this into account, we provide

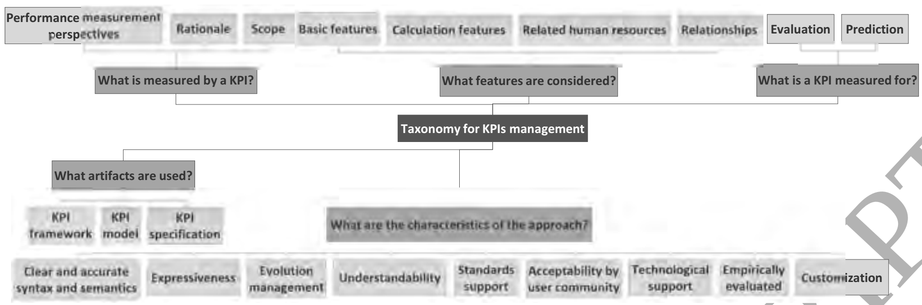

Figure 1: Taxonomy for KPIs management

a review of general background in order to give the reader with the necessary knowledge to follow the taxonomy. Additionally, we have unified the different notions distinct authors use to describe the same concepts or similar strategies.

In the following subsections, we describe in detail each dimension and its corresponding aspects, illustrating our explanations by using figures from 2 to 6, respectively, which depict the overall aspects included in each dimension. Additionally, in Table 2 we trace the papers considered from the literature to the aspects identified in our taxonomy. It is important to note that this table includes 42 references (that appear in chronological order as they were published), not the 46 that were selected as indicated in Section 2. The reason for this is that there are four works that do not present concrete proposals, but are dedicated to making comparisons, and that is why they are considered only in the comparison performed in Section 4 (9 papers in total have been used for such a comparison). In Table 2 a "✓" symbol means that the work explicitly does consider the aspect in question. Therefore we show that, while most of the works include aspects touching all the dimensions, there is no work which covers all the aspects as a whole. Thus, we provide a unified taxonomy which encompasses the overall aspects given by other proposals, and which more fully captures the characteristics of KPIs management.

Table 2: Coverage of the elements of our taxonomy by the different proposals

	1. Perspectives	1. Rationale	1. Scope	2. Basic features	2. Calculation	2. Human resources	2. Relationships	3. Evaluation	3. Prediction	4. KPI framework	4. KPI model	4. KPI specification	5. Syntax-semantics	5. Expressiveness	5. Evolution mgmt.	5. Understandability	5. Standards support	5. Acceptability	5. Technol. support	5. Empirically evaluated	5.Customization
[19]		✓	✓	✓	✓		✓	✓	✓			✓			✓	✓			✓		
[20]	✓	✓		✓	✓					✓								✓			
[21]		✓		✓	✓			✓			✓	✓									
[22]	✓			✓	✓									✓							
[23]			✓	✓	✓		✓			✓	✓								✓		
[24]			✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓						
[25]	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓		✓	✓					
[26]	✓		✓	✓	✓			✓		✓	✓								✓		
[2]		✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	✓				✓	✓	
[27]	✓		✓	✓	✓	✓		✓		✓	✓										
[28]			✓	✓	✓		✓	✓		✓									✓		
[29]	✓	✓	✓	✓	✓	✓		✓							✓			✓		✓	
[30]	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓				✓	✓				✓
[31]				✓	✓		✓	✓			✓	✓			✓	✓	✓		✓		
[32]	✓		✓	✓	✓		✓	✓		✓	✓	✓	✓			✓	✓		✓		
[33]		✓	✓	✓	✓	✓		✓		✓					✓						
[34]	✓	✓	✓	✓					✓		✓						✓		✓		
[3]		✓	✓	✓	✓	✓	✓	✓			✓	✓		✓	✓	✓	✓		✓	✓	✓
[35]	✓	✓		✓	✓		✓	✓		✓			✓		✓	✓			✓		✓
[36]	✓		✓	✓	✓		✓	✓		✓	✓	✓	✓			✓	✓		✓	✓	
[37]			✓	✓	✓		✓				✓	✓			✓	✓			✓		✓
[38]		✓	✓	✓	✓				✓		✓				✓						
[39]	✓			✓	✓		✓	✓	✓		✓	✓							✓	✓	
[40]	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓								✓		
[41]	✓	✓		✓	✓		✓	✓		✓	✓	✓							✓		
[4]		✓	✓	✓	✓						✓								✓		✓
[42]	✓	✓	✓	✓	✓					✓	✓				✓				✓		
[43]	✓	✓	✓	✓	✓					✓	✓										
[44]	✓		✓	✓	✓			✓		✓	✓										
[45]	✓	✓	✓	✓	✓		✓			✓	✓		✓		✓	✓			✓	✓	
[46]	✓	✓	✓	✓	✓			✓			✓	✓							✓		
[47]	✓	✓	✓	✓	✓		✓	✓			✓										
[5]	✓	✓	✓	✓	✓					✓	✓										
[6]	✓	✓	✓	✓	✓		✓				✓	✓	✓				✓			✓	
[48]	✓		✓	✓	✓		✓				✓	✓									✓
[49]	✓			✓	✓					✓			✓			✓			✓		
[7]		✓		✓	✓	✓	✓	✓			✓	✓							✓		
[50]	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓			✓		✓		✓		
[51]	✓	✓	✓	✓											✓						
[52]		✓	✓	✓	✓		✓	✓	✓	✓	✓								✓		
[53]	✓	✓	✓	✓	✓		✓	✓		✓	✓					✓			✓		✓
[54]	✓		✓	✓	✓	✓	✓	✓		✓		✓					✓		✓		✓

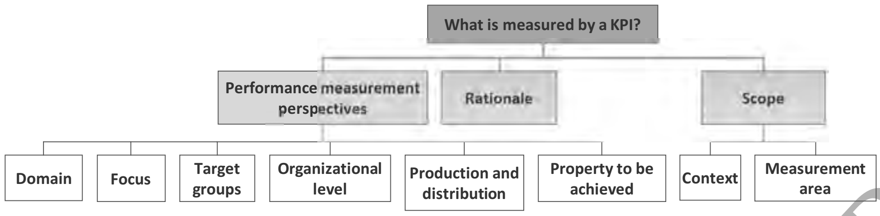

Figure 2: Aspects to be measured

3.1. What is measured by a KPI?

The most basic dimension of a KPI is that it is used to measure some aspect of a system. But even this statement has different connotations and nuances that we have identified in Figure 2. Thus, on the one hand, it is necessary to consider the different *perspectives* under which performance measures are proposed. Second, the reasons or *rationale* why an indicator has to be defined must be exposed. Finally, the *scope* must be provided to be taken into account in each case.

3.1.1. Performance measurement perspectives.

The evaluation of productivity and performance is a critical element to measure the success and improvement of any business. Since this context is so broad, there are many different perspectives under which the study of performance measurement can be considered. However, as indicated in [55], there is no consensus on the most appropriate way of categorizing these perspectives (even though that reference is restricted to the supply chain domain). Next, in order to classify the variety of approaches that can be considered, we describe several criteria that can be used to determine the measurement perspectives, giving examples of each one.

In [56] four criteria, used for perspective definition, are mentioned: *domain*, *focus*, *target groups* and *organizational level*. The *domain* criteria is related with the strategic context in which performance measures are positioned (for example, quality, cost, flexibility or innovation) [57]. The most noteworthy example mentioned in [56] that uses the *domain* as criterion for defining KPIs perspectives is the widely used Balanced Scorecard (BSC) model [20]. This model differentiates four perspectives: financial, customer, internal business process, and learning and growth perspective. Other examples of perspectives mentioned in [56], that use the *domain* as criterion, are financial/nor financial, lag/lead or external/internal. The distinction between KPIs that incorporate financial (accounting) information –such as "Return on Equity" (ROE), "Return on Investment" (ROI), and "Return on Sales" (ROS)– and those that do not, also appears in [41]. Other examples are the proposal given in [39], where authors state that performance attributes are characterized as either customer-facing or internal-facing metrics, and the proposal given in [58], where the devil's quadrangle is mentioned which includes four dimensions: time, cost, quality and flexibility. Another *domain* that has received quite an attention recently is decision making. An interesting work tackling this issue is [59], where authors identify and analyze the relationship between decisions and performance measurement from three different perspectives: (1) the impact of decisions on process performance (also studied in [60]), (2) the performance measurement of decisions themselves based on evidences gathered from the process execution, and (3) the use of process performance indicators on the definition of decisions.

As an example of the second criterion (*focus*), the differentiation between drivers and outcomes is proposed in [56]. The third criterion proposed by these authors is the *target group*, differentiating among shareholders and top management, costumer, supplier, society, environment and employee. The fourth criterion proposed in [56] is the *organizational level* in which the KPI is defined. For example, this criterion is used by [61] differentiating three perspectives: strategic, tactical or operational. As another example, the organizational layers (such as business, application and infrastructure) and the cross-cutting aspects (such as strategies and projects) are used in [29] as performance measurement perspectives. Similarly, in [47] it is remarked the interest for incorporating indicators at different levels (called *abstraction levels* by the authors). They define KPIs at the business level and also technical indicators at the applicative (IT) level, since both levels influence the overall performance of the enterprise.

Other criteria used by authors for establishing measurement perspectives are: the *production and distribution aspects* of an organization or the *property to be achieved*. Regarding the *production and distribution aspects*, in [5] authors consider that each KPI should be included in a category and a subcategory. As a consequence, each KPI is classified following two criteria, one related with the above–mentioned *domain* (for example, quality, time or cost), and another related with the production and manufacturing process (design, manufacturing, environmental or customer). An approach with certain similarities to the previous one is that presented in [40], in which authors propose a taxonomy of KPIs where two levels are considered. In this case, besides aspects related with the *domain*, KPIs are classified into six categories: manufacturing, logistics, personnel, financial, supply chain, or learning and innovation. The *properties to be achieved* are used by several authors to establish their perspectives. For example, in the Supply Chain Operations Reference model (SCOR) [62], KPIs are grouped into five categories: reliability (a task is performed as expected), responsiveness (a measure of the speed in which a task is performed), agility (the ability to respond to external influences), cost (expense of performing a process) and assets management (the ability of utilize assets in an efficient manner). As another example, measurements of operational performance (such as productivity, waste reduction of resources, or workforce turnover) are described in [34].

3.1.2. Rationale.

The *rationale* of a KPI is the description of the reasons why it is necessary to define the performance measure [41]. These reasons can be captured in different types of documents such as company policies, mission statements, business plans, job descriptions, laws or domain knowledge [2]. In these documents can appear general objectives as well as obligations that the company or institution must comply, and that therefore give rise to the need to define specific performance indicators.

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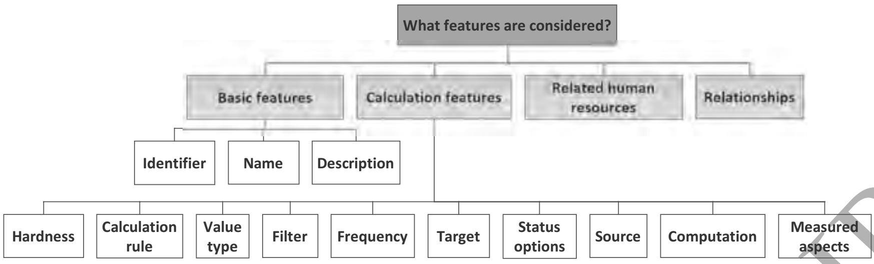

Figure 3: Features to be considered in the specification of KPIs

3.1.3. Scope.

As far as *scope* is concerned, it can be understood in two different senses. On one hand, in terms of the context of application. On the other hand, in terms of the different measurement areas the proposals are focused on.

Context. Regarding the context of application, *a priori* it is possible to consider the definition of generic KPIs, transversal to different contexts. However, they are usually defined to be used in more specific ways. The contexts can be very diverse, such as public transport systems [4], product service systems [5] or supply chain networks [6].

Measurement area. The scope of the KPIs can also be focused only on specific areas of KPIs application. For instance, in [24] authors concentrate solely on KPIs which evaluate the efficiency and effectiveness of business processes. One step further, in [3], authors define the notion of *Process Performance Indicator* (PPI) as a specialized kind of KPI focused on processes–related performance.

3.2. What features are considered in the specification of KPIs?

In order to define a specific KPI, there are different features that can be considered. These properties range from basic ones, to calculation aspects, through related human resources and relationship aspects among KPIs (see Figure 3). It is worth noting that we do not state that it is a requirement that a specific KPI comprises all these features, but we are compiling and categorizing those features proposed by the different authors. In order to better explain all these features, each aspect is illustrated with an example, taken from a specific proposal. This work is the ISO 22400 standard [63, 64], which deals with the definition of KPIs for Manufacturing Operations Management. This same proposal will be used comprehensively in Section 4 to evaluate the entire taxonomy.

3.2.1. Basic features.

The diversity of KPI definition proposals is manifested in the few properties that can be considered basic, present in many approaches, such as the KPI identifier, its name, and its textual description provided in natural language. An example taken from the ISO 22400 standard is the KPI *Effectiveness* (name) that measures *how effective a machine can be during the production time* (description) and that is represented by the letter E (identifier).

3.2.2. Calculation features.

The features that have to do with *calculation* are, in practice, the most important because they are the ones that really provide the indicator with its intrinsic nature. Among the features we have identified, we can consider the following:

Hardness. The hardness of a KPI is related to its subjective or objective nature. As described in [2], an indicator is *soft* whether it is “not directly measurable, qualitative, e.g. customer’s satisfaction, company’s reputation, employees’ motivation”, and it is *hard* whether it is “measurable, quantitative, e.g., number of customers, time to produce a plan.” The soft indicators can be measured designing questionnaires or by a combination of other (easier to measure) indicators [2, 56]. All KPIs defined in the ISO 22400, and therefore the *Effectiveness* KPI, are hard.

Calculation rule. It refers to the specific formula that gives rise to the calculation [37], and it is strongly related to the particular type of specification used in each approach (see Subsection 3.4). The calculation rule (‘formula’ in terms of the ISO 22400 standard) for the *Effectiveness* KPI is $E = PRI * PQ/APT$, where PRI stands for *Planned Runtime per Item*, PQ stands for *Produced Quantity* (in a production order), and APT stands for *Actual Production Time* (it is the actual time in which the machine is producing for an order).

Value type. Especially in KPIs of quantitative type, it is necessary to specify the type of data in which the KPI is expressed (integer, double, datetime, boolean, etc.) [19, 2], together with the unit of measure (percentage, units of weight, length, currency, etc.) [36, 40]. The ISO 22400 standard defines the *Unit of measure* of each KPI as the "basic unit or dimension in which the KPI is expressed". In particular, the *Effectiveness* KPI is a ratio, that is usually expressed as a percentage with a value of type double.

Filter. In many cases a KPI may be accompanied by one or more conditions that play the role of *filter* [24, 36]. For example, if a KPI can be calculated following a time–line, the KPI could be filtered so that its values are obtained only for a fragment of that time–line. More specific examples can be found in [3], such as *TimeFilter*, *ProcessStateFilter*, *LastInstancesFilter* or *ComposedFilter*. Likewise, limit values (in the form of *conditions*, or *quantitative limits*) could be established for the calculation of the KPI [31]. For example, in [65] the *Effectiveness* KPI is used in batch mode, so several start- and end-times are specified in order to compute the effectiveness in each batch.

Frequency. It refers to the periodicity with which the KPI is calculated [7]. It is also referred to as *time frame* in [2]. The ISO 22400 standard determines that each KPI must have a *Timing* context property, that specifies if the KPI is calculated either on *real-time*, *on demand* or *periodically*. For instance, in [65] the *Effectiveness* KPI is computed on real-time in a particular production process.

Target. Since the use of a KPI is ultimately linked to the achievement of a particular business goal, the relationship of a KPI with an associated target value is also present in many approaches [2, 3, 7, 19, 24, 39, 41, 46]. This value can be presented in an absolute form or in a range form, even with the specification of a deviation range or threshold [2, 7, 31]. As stated in works such as [24, 31], when a KPI runs out of the value range, actions to be carried out can be specified (we tackle *derived actions* to be performed in Subsection 3.3). The ISO 22400 standard indicates that each KPI can specify "the upper and lower logical limits of the KPI" through the 'Range' content property. Besides, it states that "for many of the indicators, a company specific threshold is defined".

Status options. The range of values of a KPI can be divided into several intervals, so that each interval represents a status with a particular meaning. Furthermore, in order to differentiate each status, it can be represented in a different graphic form. For example, in [7] three statuses are differentiated (good, acceptable and bad) represented by means of traffic lights. As another example, in [27] four statuses are defined by dividing the range of values by means of the *target*, the lower (or upper, depending of the meaning of the KPI) threshold and the lower (or upper) extreme value. In this case, the green, yellow, red and brown colors are used to represent each status option. Status options are not explicitly defined in the ISO 22400 (or in any of the analyzed proposals that use it). For a KPI such as *Effectiveness*, which is a ratio between planned time and real time, a possible interpretation would be to consider an optimal current value if it is greater than 98%, a good value between 94% and 98%, an acceptable value between 90% and 94%, and an undesirable value less than 90%.

Source. The source of a KPI refers to the entities, their relationships, and data and properties that are required to compute a KPI [29]. This information can be stored in databases, repositories, files and other sources. The source data for the *Effectiveness* KPI in [65] is obtained by taking the PRI parameter from the scheduling system, and by getting the APT as part of the event data in the batch management system, or by inferring it "from the process data contained in the recorded measurements (such as the current signal of a reactor that is switched on and off)".

Computation. The computation of a KPI refers to the way in which it is computed. For example, in [24], the monitor component responsible for calculating the KPIs is subscribed to the events that trigger their calculation, so that the monitor evaluates them at runtime. In [65] it is stated that "one of the most straightforward ways of computing" the APT parameter is by means of a non–trivial algorithmic procedure comprising several steps. As mentioned, the APT parameter is one of the elements required for the computation of the *Effectiveness* KPI.

Measured aspects. KPIs can also be categorized according to the concrete aspect being measured. This question is closely related to the issues referred to in Subsection 3.1, but it is often possible to indicate at this level whether it is an indicator that measures duration, frequency, fulfillment of a certain condition, object's property, resource, cost, quality, etc. [3, 21, 31]. Additionally, the *processes linked to a KPI* could also be mentioned, since they can refer to *related processes*, *related process instances* or even *required process instances* [3]. In the ISO 22400 standard, the 'Production methodology' context property specifies if each KPI is generally applicable for discrete, batch or continuous systems. As previously presented, in [65] it is used in a batch production system.

3.2.3. Related human resources.

There are different people, roles or even departments within an organization involved in the development of a KPI. For example, the *owner* can be considered, that is, "a stakeholder in the enterprise responsible for the achievement of a defined KPIs" [29]; the *responsible* person, referring the one who is in charge of the indicator being calculated [3]; and the *informed* person, that is, who is interested in the KPI and should be informed of its results [3]. The ISO 22400 standard uses the term 'Audience' to refer to the user groups that typically utilize the KPI. In particular, it distinguishes between *Operators*, *Supervisors* and *Management*.

3.2.4. Relationships.

Dependencies between KPIs can be explicitly specified representing, for example, the components used in the computation formula [36]. This kind of relationships among components can lead to *basic* KPIs, *compound or derived* KPIs (such as the sum or the ratio of two existing indicators) or *aggregated* KPIs (for example, the average of other indicators). With different nuances, this notion of 'granularity' appears in the majority of approaches [2, 3, 6, 19, 24, 31, 36, 37, 39, 40, 45]. As other examples, the self–explanatory pair "givesDataTo" and "takesDataFrom" relationships are defined in [30]. Furthermore, drill-down operations with the KPIs are enabled making use of these relationships [45, 53].

The ISO 22400 standard does not establish explicit relationships between KPIs. However, in [66] it is indicated that "KPIs should be categorized", and in particular, distinguishes between 'basic' and 'comprehensive' (i.e. derived) KPIs. For instance, the *Overall equipment effectiveness index (OEE)*, is a comprehensive KPI defined as $OEE = A * E * QR$, where A is the *Availability* KPI, E is the *Effectiveness* KPI, and QR is the *Quality Ratio* KPI. Besides, in [66] it is stated that "since one [measurement] element can be used in the definitions of several KPIs, it is impossible that KPIs are independent with each other". Authors specify two types of relationships, the first based on the definition of KPIs themselves, and the second based on "relevance with shared supporting elements that can be obtained by pairwise comparison".

We have to remark that although other optional features may be considered in the specification of KPIs, we have not explicitly included them in the taxonomy mainly for being scarce the number of works which mention them. Among such features, we note for example *literature references* [29], *notes* [41] and *heuristics* obtained from practice [29].

3.3. What is a KPI measured for?

KPIs can be used with several purposes which we have classified in two groups taking into account whether their aim is to *evaluate* the performance (past or present [30]) of a monitored system, or to *predict* the future behavior of a system. A similar idea is proposed in [19] differentiating between the capability of getting explanations for why a certain metric has a certain value, and for predicting the future value for a metric on a process execution. More specifically, in Figure 4 we depict the different aspects identified in this dimension. It must

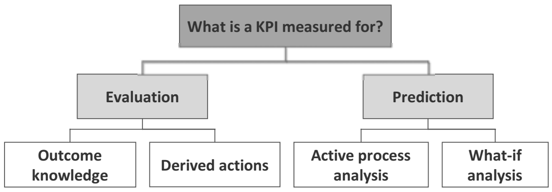

Figure 4: Aim of the KPIs definition

be noted that these two purposes are not exclusive, so that the same KPIs can be used for evaluation and prediction.

3.3.1. Evaluation.

Outcome knowledge. The evaluation can be performed in order to obtain knowledge about the past or about the present of an organization [30]. On the one hand, *past knowledge* can be derived by evaluating the historical data of the company. For example, a trend can be discovered making use of business intelligence tools like data warehousing and data mining [39]. On the other hand, *present awareness* is deduced by analyzing the current value and the current status of the defined KPIs. This information is relevant in order to know the current situation of the company and, for example, comparing it with other similar companies.

Derived actions. It refers to the actions to be triggered if a particular measure does not achieve the desired target value [31]. For example, two different elements can be specified: (1) *message* [31] or *alert* [24] for notifying the situation to the responsible business users or decision makers, and (2) *operation* to be performed regarding the involved processes (abortion, suspension or start of a new process) [31].

3.3.2. Prediction.

Active process analysis. Predictive analysis on metric values of the active process instances can help to make decisions proactively anticipating or reducing possible problems that may occur. For example, a decision tree of the different

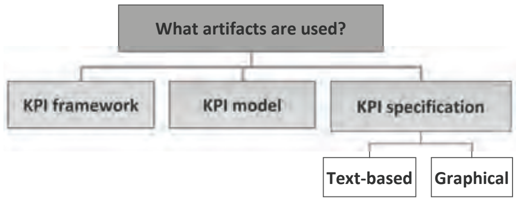

Figure 5: Artifacts that are used

elements that influence what is happening can be created (critical factor analysis) or the effect of failures that are occurring can be calculated in order to avoid or reduce their negative effect (impact analysis) [19].

What–if analysis. Prediction of future metric values taking into account different alternatives enables companies to better plan improvement strategy and improve their responsiveness [39]. For example, KPIs can be used together with simulations in order to foresee several possibilities to search for the most optimal (optimization) or to anticipate a given future plan to know the results that could be obtained (scenario analysis) [19]. In [38], simulations are performed to calculate the environmental impact of urban planning actions. In [67], KPIs are calculated as a result of a business simulation and thus analyze the possible effect (attempting to mitigate socio-economic problems).

3.4. What artifacts are used for KPI design and specification?

The definition, use and management of a KPI are tasks that can hardly be developed in isolation. They are usually carried out using a *framework*, a specific *modeling technique* and/or a *specification proposal.* In Figure 5 we present the different aspects identified in this dimension.

3.4.1. KPI framework.

The framework within KPIs are defined is related to the overall work context that is used in each particular approach. Frameworks such as the Building Information Modeling (BIM) framework [68], the Balanced Scorecard [20] or Performance Prism [33] specially stand out. Although these frameworks, as such, do not necessarily have to be focused on the definition of KPIs, they provide a conceptual and technical setting that determine the style of definition of the indicators.

3.4.2. KPI model.

In many cases, in addition to the general framework, a concrete modeling technique is used. Modeling techniques can be presented in very different ways. For instance, profiles [42] or metamodels [3, 37, 43, 48] can be specified. General models in the business context, such as Business Intelligence Model [27] or Business Strategy Model [32], or more specific ones such as the Supply Chain Operations Reference model (SCOR) [62] are also considered. Regarding ontologies, there exist very specific ones (such as *KPIOnto* [45]) but, as highlighted in [69], defining an ontology constitutes a cumbersome task so that, whenever possible, existing ontologies can also be reused.

3.4.3. KPI specification.

There are also different options for the particular format in which KPIs are specified. We can basically distinguish between two non–exclusive possibilities: *text–based* and *graphical*, which can be combined with the use of templates. The specific language in which the specification is made can also be very varied, from the specification in natural language to the use of formal languages, through the use of domain–specific languages of specification. As way of example of KPI specifications, we cite the following: regarding *text-based* proposals, we note those based on SQL [37, 48], on SPARQL [6, 46], or on MDX [7, 39]. Approaches which consider a graphical specification are [3, 31], while templates are used in [19].

3.5. What are the characteristics of a KPI management approach?

In order to justify the validity or quality of the KPI management approaches, the characteristics enumerated by the authors with regard to their approaches are diverse (see Figure 6). These characteristics range from conceptual aspects, such as syntax or semantics, to technical aspects, such as tool support or code

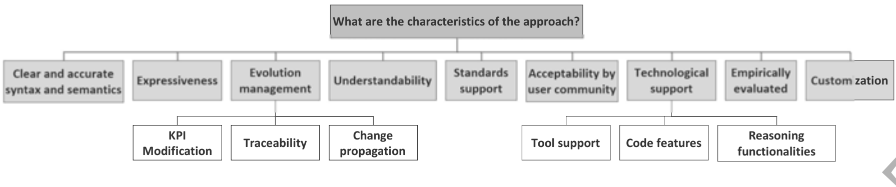

Figure 6: Characteristics of a KPI management approach

features. The success of a proposal will depend, to a large extent, on the degree of compliance with the characteristics indicated in this section.

3.5.1. Clear and accurate syntax and semantics.

The definition of an unambiguous syntax and semantics of the language, textual or graphical, for specifying the KPIs is crucial in order to calculate correctly what the user wants to measure [35].

3.5.2. Expressiveness.

The proposal should be able to express a broad spectrum of KPIs, providing a solid basis for defining KPIs in any organization. Besides, the SMART criteria can be used for evaluating the information included in the KPIs specification [3]. SMART is an abbreviation of five criteria for goal suitability [22]: Specific (detailed and clear), Measurable (unambiguous), Attainable (reasonable and challenged), Realistic and Time-sensitive (with a time frame for completion). Therefore, a KPI specification proposal should include all the information that is necessary to define indicators according to the SMART criteria [3].

3.5.3. Understandability.

In order to facilitate both the specification and the subsequent use of KPIs, it is important to provide a readable and understandable language [35]. This is not an easily achievable feature since different actors are involved in the KPIs development (decision makers, business analysts or stakeholders), each one with different technical levels and background, and practical requirements. For example, a formal and mathematical notation is not suitable for non–expert users.

3.5.4. Standards support.

The proposal must take into account the application field in order to provide support to the most outstanding de-facto standards within that field. This aspect would have a high influence in the success of the proposal. For example, within the Business Process Management (BPM) field, the support of standard business process notations such as BPMN or BPEL must be considered [3].

3.5.5. Acceptability by user community.

A proposal that meets the most demanded properties is not always the most attractive or the finally chosen option. The characteristics of the target community must be considered and pragmatic aspects must be taken into account [12]. For example, works [20, 29] explicitly assess acceptability through qualitative feedback given by domain experts.

3.5.6. Empirically evaluated.

Practical evaluations must be performed in order to validate the applicability of the proposed approach in an organizational context. These evaluations are very varied, for example, in [69] evaluations performed through case studies or examples are differentiated. Furthermore, the characteristics evaluated are also very varied such as maintainability [2], applicability to different scenarios [3, 29], practicality [6], effectiveness and efficiency [45], evaluation of costs [36] or benefits of the proposed approach [36].

3.5.7. Customization.

The particular circumstances of each company make it necessary to adapt general KPI definitions to deal with the situation at hand. For example, within the data warehouse context, pre-configured reference models and the corresponding KPIs definitions must be customized, tailoring them to the specific needs of the individual company [37]. In particular, the BIRD approach [37, 48] includes an abstract syntax, described as a metamodel, for KPI customization (at design time). The metamodel specifies the elements that can be redefined (predicates, arithmetic measures, cumulative measures and conditions), so that the original calculation rule is overridden.

Moreover, contemporary organizations, within themselves, have to deal with different priorities and customs being necessary to maintain multiple variants of the same business process [70], and, as a consequence, supporting the variability of KPIs [71]. For this reason, there are approaches that provide structured customization mechanisms for covering business process variability [70] and that facilitate the maintenance of several KPI variants at the same time [71].

3.5.8. Evolution management.

Business requirements are not static along the life of a system, but they change and evolve over time, in order to adapt the system to several circumstances, such as changes in the goals of the enterprise or modifications of the business processes. For this reason, the KPIs definition must evolve accordingly to the system requirements. As a consequence, a KPI management approach would have to be provided with mechanisms that allow KPI evolution processes to be accomplished. Three different characteristics, explained below, can be involved for performing evolution tasks: *KPI modification*, *traceability* and *change propagation*. The more features a KPI setting provides, the easier it will be to carry out the evolution process.

KPI modification (adaptation to change). The KPI management setting must provide mechanisms for modifying the KPIs definition, from something as simple as changing the name of a KPI [37], to something as complex as modifying the calculation rule [45]. In this way, changes that occur over time in the company can be reflected in the KPIs definition. The same mechanisms defined for KPIs customization could be used for their modification.

Traceability. In a broad sense of the term, traceability is related to maintain and manage information about the elements that influence, or are influenced by, the KPIs definition. These elements can be, for example, the strategic goals of the company that motivated their definition, the elements used for their calculation or the dashboards which visualize them. The existence of an explicit link between the KPIs and the related elements is a feasible way to support traceability. In this sense, several components of the KPIs definition mentioned in previous sections, such as *rationale*, *calculation aspects* and other elements, allow traceability to be addressed. For example, the KPI specification language proposed in [31] provides connection points to both the process (or process element) and the dashboard elements, thereby facilitating the identification of necessary adaptations in case of changes. Moreover, in [3] not only the relationship between Process Performance Indicators (PPIs) and business process elements is established, but also analysis operations for extracting information from these relationships are implemented. This information is useful for accomplishing business process evolution tasks maintaining coherence between business process models and PPIs.

Change propagation. In addition to KPI modification and traceability, a more complex feature is change propagation. To support this characteristic, the KPI management framework would provide mechanisms to automatically check consistency between the KPIs and their related business elements, as well as an incremental update mechanism. Thereby, any change in the elements that influence a KPI definition may trigger its redefinition and, on the contrary, a KPI modification may provoke the adaptation of the affected elements. For example, in [3], the operation "AssociatedPPIs" is used to obtain the information about which are the PPIs that would be updated when a certain process is modified.

3.5.9. Technological support.

A very important requirement is that the proposals not only would need to remain at a theoretical level but also they would have to provide technological support with automatic mechanisms that facilitate the management of KPIs. Next, we describe those technological support aspects proposed by the different authors.

Tool support. This characteristic refers to whether the proposal gives support for the definition of KPIs by means of a tool. Several properties of such a tool can be identified, for example, (1) KPIs can be modeled by referencing business elements [24], (2) KPIs can be defined in a graphical way [3, 31] or, at least, in a conceptual way (understandable by non-technical users), and (3) the tool provides a uniform view over KPI data, independently of the original data sources, relying on back-end services that rewrite and resolve such requests as queries over the persistence system [36]. The generation, automatic or semi–automatic, of executable code is also included in this aspect (e.g. [7]).

Code features. Several quality criteria have been proposed in the software engineering literature to evaluate the software code. For example, in [7], authors consider *scalability* (ease to maintain and evolve), *portability* (deployment in different platforms) and *extensibility* (ease to add or modify features) as relevant properties of KPI code.

Reasoning functionalities. Reasoning support allows new knowledge to be inferred from the original domain body [69]. Regarding the definition and analysis of KPIs, tools providing automated reasoning mechanisms are highly recommended [3, 45]. Two different types of reasoning design-time support can be differentiated: *functionalities based on the relationships among KPIs* and *functionalities based on the relationship between KPIs and other elements* [3].

As examples of the first type of functionality, several authors propose mechanisms for checking consistency among KPIs [3, 37, 45] and formula rewriting [36]. For example, in [45], formal definitions and automatic reasoning tools are used so that, any time a performance indicator is added, updated or deleted, three properties for consistency assurance are checked: uniqueness (formulas have different definitions), inequivalence (equivalent formulas are detected) and coherence (there are no contradictions).

Regarding the second type of functionality, in [49], the automation of the process for automatically deriving KPIs from organizational objectives is mentioned. Furthermore, automated analysis of relationships between indicators and business elements [3] or activities [52] are proposed. For example, in [3], a design-time estimation of business process elements that have an influence on a

PPI is automatically obtained, so that, among other things, different PPIs configurations can be analyzed trying to cover the most relevant business process elements.

4. Discussion

According to [72], "the search for the best, or optimal, design is often intractable for realistic information systems problems". In this respect, in [16] authors state that taxonomies need to be evaluated for their usefulness, and they determined a set of sufficient qualitative attributes that identify a useful taxonomy. Following this idea, firstly we evaluate our taxonomy using these attributes which correspond to the *subjective* ending conditions (*concise*, *robust*, *comprehensive*, *extendible*, and *explanatory*). Furthermore, as a second evaluation criteria, we compare our taxonomy with other works devoted to identify KPI management characteristics proposed in the literature. Finally, we have analyzed, under the prism of our taxonomy, a concrete KPIs proposal as use case, in order to assess the coverage degree of the aspects addressed.

4.1. Evaluation criteria of the taxonomy

Our particular taxonomy satisfies the subjective ending conditions proposed in [16]. Next, we discus each of these conditions:

Concise. "A taxonomy should contain a limited number of dimensions and a limited number of characteristics in each dimension..." [16]. The proposed taxonomy contains a *concise* number of dimensions and aspects, so that it can be easily comprehended and applied. More specifically, according to [16], the number of dimensions and characteristics could be assessed by comparing them with the maximum amount of input information suggested by research on cognitive capacity in decision making, for instance, seven plus or minus two [73]. In this context, our taxonomy is concise with 5 different dimensions, each one including between two and nine aspects.

Robust. As stated in [16], "a useful taxonomy should contain enough dimensions and characteristics to clearly differentiate the objects of interest". The proposed taxonomy is *robust* enough to adequately differentiate the distinct aspects involved around KPIs management. In particular, with our 5 dimensions and 21 first-level aspects (including also 33 second-level aspects), we defined and portrayed each dimension and aspect as a distinct attribute of a KPI management criterion. Thereby the proposed taxonomy proves robust in differentiating among aspects involved around KPIs management.

Comprehensive. "A useful taxonomy can classify all known objects within the domain under considerations" [16]. At this respect, taking into account the wide number of papers considered during our review process (both those analyzed and selected), we are confident that the most important and widely considered aspects involved around the KPI field are covered by our taxonomy. In this context, we also note that the ratio of the number of newly added aspects and the number of characteristics merged with existing aspects (for example, two proposals containing two similar or identical aspects), decreased with each inductive iteration, which indicates a saturation of covered aspects.

Extensible. It refers to the fact that "a useful taxonomy should allow for inclusion of additional dimensions and new characteristics within a dimension when new types of objects appear" [16]. Future advances in KPIs (both in application and in research) would make not only necessary but also possible to *extend* the taxonomy. We think that identifying our dimensions following a question–based strategy eases the inclusion of additional dimensions and new aspects within a dimension when new types of objects appear. More specifically, when a new aspect concerning KPIs management appears and it does not match any of the identified questions (that is, it results in a negative answer), then a new question-based dimension could be included as part of the taxonomy, which should consider at least such an aspect as characteristic of the new dimension. We note that it would be advisable that such a question is formulated as general as possible so that it does not adjust too much to such a concrete aspect. However, if such a new aspect does match an identified question (that is, it results in an affirmative answer), and it does not merge with existing aspects, it could be included as an additional aspect of the dimension.

Explanatory. This ending condition assesses "what dimensions and characteristics explain about an object" [16]. We consider that this condition is met for several reasons. First, we think that the explanatory value of the taxonomy is best illustrated by the fundamental question each dimension answers regarding KPIs management (as described at the beginning of Section 3). Second, the taxonomy provides useful *explanations* of the dimensions and essential aspects concerning KPIs management included in each dimension, so that an aspect found regarding KPIs managements can be readily categorized. For instance, [54] presents a table that summarizes "the fields that are provided in the description of any KPI in the ISO 22400 standards". By contrasting each of these fields with the dimensions and aspects of our taxonomy, these fields can be categorized in a simple way (as explained in Subsection 3.2 for the "What features are considered?" dimension, and it will be shown more comprehensively in Subsection 4.3). As another different example, a tabular presentation can also be found in [7], in this case to present a specific KPI (called "Quality of Service"). The use of our taxonomy allows the exploration of the elements of the table, called "KPI definition sheet", to explain to which category each of these elements belongs. The comparison (of the tables) of both approaches in light of the dimensions and aspects of our taxonomy can demonstrate differences among them. For instance, a *filter* aspect is included in the ISO 22400 (through the 'Production Methodology' property), aspect that it is not included in the "Quality of Service" KPI.

In addition to these necessary generic conditions, in [16] authors also note that determining sufficient conditions for usefulness depend on the expected use of the taxonomy, and that this usefulness relies on if others use it over time. Regarding this, the evaluation of our taxonomy by experienced users constitutes a line of future work.

4.2. Comparison with other proposals

While in the literature there is a large and heterogeneous research corpus of approaches to address the management of KPIs, there is not much literature devoted to compare different proposals, with the goal of identifying a KPI management structured knowledge. Next, we describe the comparison we have performed, using Table 3 to illustrate our explanations. In this table we use the same notation than in Table 2, while in Appendix A we have included Tables A.4 and A.5 with complete explanations.

More specifically, the most systematic approaches are proposed in [69] and [56] which develop a systematic literature review on performance measurements. In [69], the authors perform a bibliometric analysis and classify the selected articles by means of a comparison framework. The bibliometric analysis concerns several aspects, such as the number of papers, authors and citations per year, which does not fall within our proposal. With regard to the proposed comparison framework, the authors classify the different proposals according to the modeling method, the object and extent of analysis, and the level of granularity. Furthermore, this work presents other five characteristics to compare exclusively the ontology-based proposals: methodological approach, re-use, reasoning functionalities, aim and expressiveness. On the other hand, in [56], the authors perform a categorization of business process performance measurements proposing 11 performance perspectives. The paper also documents a list of 140 performance indicators categorizing them into the proposed perspectives. Comparing these two proposals with our work, we note that they mainly focus on answering, in a partial way, the first and fourth questions of our taxonomy.

A comparison framework is also presented in [3], but in this case only proposals for evaluating the performance of business processes are compared. In this case, the comparison includes the requirements established by the authors as suitable for an appropriate definition of Process Performance Indicators: expressiveness, traceability and automated analysis. Furthermore, tool support and support for BPM standards are also compared. It can be seen in Table 3 that these characteristics correspond, to a great extent, to the other three ques-

Table 3: Comparison of the selected works

	[69]	[56]	[3]	[57]	[53]	[29]	[61]	[7]	[35]
1. Perspectives		✓		✓	✓		✓		
1. Rationale	✓			✓	✓	✓	✓		
1. Scope. Context	✓	✓					✓		
1. Scope. Measurement area	✓	✓			✓		✓		
2. Basic features						✓			
2. Calculation. Hardness									
2. Calculation. Rule					✓	✓			
2. Calculation. Value type					✓				
2. Calculation. Filter			✓						
2. Calculation. Frequency			✓	✓		✓			
2. Calculation. Target						✓			
2. Calculation. Status options						✓			
2. Calculation. Source					✓	✓			
2. Calculation. Computation									
2. Calculation. Measured aspects			✓		✓				
2. Related human resources						✓			
2. Relationships			✓		✓				
3. Evaluation. Outcome knowledge					✓				
3. Evaluation. Derived actions						✓			
3. Prediction									
4. KPI framework		✓						✓	
4. KPI model	✓	✓			✓		✓	✓	
4. KPI specification	✓				✓			✓	
5. Clear and accurate syntax and semantics									✓
5. Expressiveness	✓		✓						
5. Evolution. Modification									
5. Evolution. Traceability			✓		✓	✓			
5. Evolution. Propagation									
5. Understandability									✓
5. Standards support			✓						
5. Acceptability									
5. Tech. Support. Tool			✓						✓
5. Tech. Support. Code features									✓
5. Tech. Support. Reasoning functionalities	✓		✓						
5. Empirically evaluated	✓	✓		✓					
5. Customization									

tions of our taxonomy not considered by the previously mentioned works of [69] and [56]. Thus, it can be concluded that these three comparison frameworks are quite complementary.

An excellent overview of performance measurement systems is provided in [57] defining several performance perspectives and key considerations for analyzing a performance measurement system. This proposal is mainly concerned with the first and fifth questions of our taxonomy, nevertheless, unlike ours, this overview also provide steps and guidelines to design a performance measurement system. Moreover, in [53] several KPI measurement systems are compared according to two sets of criteria, one related to the KPI modelling and another related to the KPI analysis framework. When considering these two sets of criteria in light of our taxonomy, we conclude that they belong to four different questions.

A more specific comparison is proposed in [29] which focuses on determining a unified specification for KPIs within the field of Enterprise Architecture (EA) management. An EA management literature study is conducted, analyzing the proposed elements for KPI descriptions, followed by a qualitative feedback given by domain experts. As a result of this research, a structure for KPI specification is established which contains two types of elements: (1) general structure (GS) elements independent from any enterprise context, such as title, description or calculation, and (2) organization-specific (OS) elements, such as mapping with the organization-specific concepts, frequency or KPI owner. Finally, the related literature is examined, validating which elements of the designed structure are covered by each proposal. Since the purpose of this article is very specific, this comparison is mainly concerned with only the second and third questions of our taxonomy, leaving out aspects related with the rest of questions.

Other three papers propose more delimited comparisons, analyzing aspects mainly related with only one of the questions of our taxonomy. Within the field of supply chain performance models, the work presented in [61] is mainly concerned with comparing what is measured (first question) in each of the proposals. Most of the comparison elements are used to differentiate the measured aspects. In this case, our taxonomy has served to bring to light that (1) performance aspects and source are mixed in the 'degree of conceptualization' element, and that (2) performance aspects and scope are mixed in the 'conditions and constraints' element. On the other hand, the comparison proposed in [7] is concerned with the techniques used for modeling and calculating KPIs (fourth question): framework, model, expression and code. And finally, in [35] authors propose and compare four characteristics required for a good KPIs representation (fifth question): (i) proficiency in computational tractability, (ii) clear and accurate syntax and semantics, (iii) stakeholder understandability, and (iv) extensibility.

There are other works, not included in Table 3, which also compare different KPIs proposals, but they are very simple or they have a different aim than ours. In [49] authors simply perform a comparison of proposals with regard to the objective-KPI relationship (question fourth: traceability) and assisted KPI derivation (question fourth: reasoning functionalities). In [74] a comparative review is followed classifying the KPIs into four general representative classes according to only the different aspects to be measured (first question: measured aspects). In the same way, a taxonomy of measures is provided in [55], delineated according to: the involved processes, what they measure and whether they are quantitative or qualitative (first question).

We can conclude that our taxonomy covers completely the analyzed related work in this section, including even aspects that have not been contemplated by other authors. Especially remarkable is the absence in other comparisons of aspects related to customization and evolution (adaptation and propagation) of KPIs, which are clearly needed to manage the performance of ever–changing systems.

4.3. Use case: the ISO 22400 standard

As last evaluation method, in this section we analyze a particular KPIs proposal in light of our taxonomy. The selected proposal is the ISO 22400 standard "Automation systems and integration - Key Performance Indicators (KPIs) for

Manufacturing Operations Management". This standard is a current and very ambitious work that describes a list of 34 KPIs which can be used in manufacturing industry. Parts 1 ("Overview, concepts and terminology") [63] and 2 ("Definitions and descriptions") [64] of the standard were published in 2014, and already at that time parts 3 ("Exchange and use") and 4 ("Relationships and dependencies") were planned. In 2017 an addendum to part 2 was published, on "KPIs for energy management" [75]. And very recently, in October 2018, part 10 of the standard on "Operational sequence description of data acquisition" [76] has been released. The publication of the standard has attracted interest in the community, and there are several recent studies that work around the ISO 22400. As a curiosity, it has been used as a source of inspiration for the proposal of similar frameworks in other contexts such as industrial performance improvement [77] or definition of indicators for software industry [78]. We have explicitly considered some remarkable works (specifically [54, 65, 66, 79]) in the evaluation of the proposal as use case.

What is measured by KPIs in the ISO 22400?. Regarding the *performance measurement perspectives*, it is clear that the ISO 22400 standard belongs to the internal, non-financial domain, and that the Manufacturing Operations Management (MOM) level is a tactical level from the organizational perspective.

A global *rationale* is described in [64] since the specified KPIs "are very important for understanding and improving manufacturing performance, both from the lean manufacturing perspective of eliminating waste and from the corporate perspective of achieving strategic goals".

The *context* of the KPIs defined in the standard is 'Manufacturing Operations Management (MOM)'. This is Level 3 in the functional hierarchy model of a manufacturing enterprise, model that also includes 'Business Planning and Logistics' as Level 4 and 'Batch, Continuous and Discrete control' as Level 1-2. Indeed, the described KPIs are located specifically at Level 3: "KPIs related to business planning and logistics [...] are outside the scope of this part of ISO 22400" [64]. Besides, some works propose to group the KPIs with structures (*measurement areas*) different from those of the standard. For instance, in [66] basic KPIs are categorized in three groups: ‘production’, ‘quality’ and ‘maintenance’.

What features are considered in the specification of KPIs in the ISO 22400? With slight differences with respect to the chosen names, the majority of the features that we have described in our taxonomy are also explicitly included in the standard (see examples in Subsection 3.2). The *basic* features ‘Name’, ‘Identifier’ (‘ID’) and ‘Description’ are included as-is. Regarding the *calculation* features, the *calculation rule* is ‘Formula’ in the ISO; the *value type* is ‘Unit of measure’; the *frequency* is ‘Timing’; and the *Target* is considered under the ‘Range’ property. The other calculation features are also present, although in an implicit way. For instance, the need of a *source* is evident since the KPIs “are intended to be calculated using data from the control domain, and to provide both the enterprise domain and the MOM domain with decision support information to manage the enterprise” [63]. Another evidence regarding *source* is the title of the Part 10 of the standard: “Operational sequence description of data acquisition” [76].

The *related human resources* feature is also explicitly considered through the ‘Audience’ property, that distinguishes between three user groups for KPIs: ‘Operators’ (“personnel responsible for the direct operation of the equipment”), ‘Supervisors’ (“personnel responsible for directing the activities of the operators”) and ‘Management’ (“personnel responsible for directing the overall execution of production”) [54].

The existence of *relationships* between KPIs is evident given that the elaboration of a part of the standard precisely called “Part 4: Relationships and dependencies” is foreseen [63]. In the meantime, the ‘Effect model diagram’ element is a “graphical representation of the dependencies of the KPI elements” [54]. Finally, the work [66] is specifically devoted to create a hierarchical structure of the KPIs of the ISO, in order to “group the KPIs into multiple categories in various levels, which have explicit cross links”.

What is a KPI measured for in the ISO 22400? Regarding the *evaluation* uses, the ISO specifies the 'Trend' property, that "is the information about the improvement direction, higher is better or lower is better" [54]. The 'Effect model diagram' must be also considered here for its relation with the *derived actions* element, since this diagram "is a quick analysis which supports rapid efficiency improvement by corrective actions". Another *evaluation* example is stated in [65]: "the consequences of a KPI deviating from its target value can be a) to improve the production and therefore impact on the actual production performance or b) to adjust the planned values according to historical data" (i.e. *present awareness* and *past knowledge*).

As far as we know, neither the standard nor any of the works considered refer to *prediction* aspects. This is where one of the possible utilities of our taxonomy is demonstrated: when analyzing a proposal considering all the elements of the taxonomy, aspects not contemplated in that proposal can be found. Depending on the cases, these omissions could show shortcomings in the proposal or, at least, possible future lines of improvement.

Finally, it is worth noting that Part 3 of the standard (not yet released) is called "Exchange and use", so it is to be expected that this document will include some indications as to what KPIs can be used for.

What artifacts are used for KPI design and specification in the ISO 22400? In a straightforward way, the ISO 22400 is not tied to any specific framework, model or specification, beyond that it is anchored to the ISO standards development rules. Each particular approach may determine these aspects. Thus, for example, the proposal of [54] is *framed* within the consideration of a Knowledge Based System. In that work, an ontology is specified through a UML class diagram (*model*), and a specific XML-based *specification* language is used, called Key Performance Indicators Markup Language (KPIML). As an aspect to emphasize, let's recall that the effect model diagram is a "graphical representation of the dependencies of the KPI elements".

What are the characteristics of the KPI management ISO 22400 approach?

Among the multiple elements that appear when it comes to analyzing the characteristics of each approach, it should be noted that we are dealing with an obvious case of *standards support*. In addition, each of the different works treasure some of the characteristics exposed. For example, in [54] the focus is on implementing (related to *technological support*) and visualizing (related to *expressiveness* and *understandability*) the KPIs of the standard. The approach of [79] pursues the practical applicability (i.e. *empirically evaluated*) of the standard. In order to get such applicability, several particular ways of defining some KPIs are described, so *customization* procedures are specified. Even though it cannot be considered a scenario of *evolution management*, in [66] several KPIs are redefined with respect to the same of the standard, which is undoubtedly an example of *modification* of KPIs. The very existence of various works based on the standard is a clear sign of *acceptability by users community*.

5. Conclusions

The existence of a large and heterogeneous research corpus of approaches to a particular field of knowledge can have two contradictory effects. On one hand, it is an evidence of that the subject is of interest to the community, both researchers and practitioners. But on the other hand, it can hinder to find a consensus or common ground for even the most basic concepts.

This situation is fully applicable to KPIs management. This is a field with a strong component of practical application since a suitable and solid set of KPIs can contribute to generating tangible value in any organization. This has led to a rapid growth of research devoted to the KPI field, with a wide diversity of approaches that tried to set what requirements a KPI should fulfill, what elements are involved in formalizing the concept of a performance indicator, or what relations to other concepts such as goals, processes, and roles are needed.

In order to contribute to a better understanding of the field, and to advance towards a consolidation of knowledge, in this paper we have presented a taxonomy of issues related to KPIs management, focusing mainly on KPIs definition aspects. To make it easier the use of this taxonomy, and drawing on other taxonomies present in the literature, we have organized it following a question–based strategy. Our unified taxonomy encompasses the overall formalization aspects considered by other proposals, and it captures the unique characteristics of KPIs in a more fully way. Thus, this work is intended to provide several benefits. First, our taxonomy and review of related background enhances the understanding of the field to potential researchers, practitioners or KPIs' users. Second, the results can be particularly relevant for potential researchers aimed at identifying research issues regarding the definition of KPIs that have been already tackled or directions for future research. Third, some future lines of improvement (or even shortcomings) can be detected when analyzing each KPIs particular proposal in light of our taxonomy. Last but not least, our approach enables KPI users to distinguish between different perspectives of KPIs definition and guide them in their decision towards the specification of concrete KPIs.

One of the main results of the taxonomy we have presented is to gather and to consolidate, to a certain extent, the existing knowledge and terminology in the KPI field. However, every taxonomy is dynamic and could be modified along the time. Thus, as described previously, advances in KPIs, both in application and in research, would make it not only necessary, but also possible to keep the taxonomy constantly updated. Additionally, in future research, we plan to evaluate the taxonomy by discussing it with experienced users, researchers as well as practitioners, inducing possible adaptations of the taxonomy

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Appendix A. Detailed characteristics of other proposals

Tables A.4 and A.5 show a detailed comparison of the selected works devoted to compare different proposals with the goal of identifying KPI management structured knowledge.

Table A.4: Detailed comparison of the selected works (1/2)

	[69]	[56]	[3]	[57]	[53]	[29]
1. Performance measurement perspectives		Perspectives. Functionality (categories)		Strategic context: quality, time, cost and flexibility. Efficiency and effectiveness. Internal and external environment	Level	
1. Rationale	Organizational goals/Only indicators			Applications	Goal coverage	General Structure Elements. Goals
1. Scope. Context	Single/collaborative enterprises	Domain or sector				
1. Scope. Measur. area	Subject (PPI, KPI)	Scope			KPI coverage	
2. Basic features						General Structure Elements. Title, description, code
2. Calculation. Hardness						
2. Calculation. Rule					Metric formula	General Structure Elements. Calculation
2. Calculation. Value Type					Measurability	
2. Calculation. Filter			Expressiveness. Number of instances, temporal, state scope			
2. Calculation. Frecuency			Expressiveness. Temporal scope	Periodic benchmarking		Properties. Frequency
2. Calculation. Target						Properties. Target, planned, tolerance
2. Calcul. Status options						Properties. Interpretation
2. Calculation. Source					Information sources. Measurement origin	General Structure Elements. Information model
2. Calcul. Computation						
2. Calculation. Measured aspects			Expressiveness. Time, count, condition, data measures		Measurability	
2. Related human resources						Properties. Consumer, Owner
2. Relationships			Expressiveness. aggregated, derived measures. measured by, involved in		Drill-down technique	
3. Eval. Outc. know.					Evaluation technique	
3. Evaluation. Derived actions						Properties. Escalation rule
3. Prediction						
4. KPI framework		Foundations				
4. KPI model	Modeling method (DSML or Ontology). Ontology. Re-use of existing ontology	Artifact. Functionality (models)			Semantics	
4. KPI specification	Ontology. Methodological approach: Language				Semantics	
5. Clear and accurate syntax and semantics						
5. Expressiveness	Ontology. Expressivity		Expressiveness. SMART			
5. Evol. Modification						
5. Evol. Traceability			Traceability		Goal coverage	Mapping
5. Evol. Propagation						
5. Understandability						
5. Standards support			BPMN standard support			
5. Acceptability						
5. Tech. Tool support			Tooling support			
5. Tech. Code features						
5. Tech. Reasoning functionalities	Ontology. Reasoning functionalities		Automated analysis			
5. Empirically evaluated	Ontology. Methodological approach: evaluation	Evaluation method		Criteria and principles		
5. Customization						

Table A.5: Detailed comparison of the selected works (2/2)

	[61]	[7]	[35]
1. Performance measurement perspectives	Type of analysis; Conditions and constraints; Degree of conceptualisation; Established indicators; Human capital; Sustainability; Decision level; Level of supply chain maturity; Quality factors; Type of bench-marking		
1. Rationale	Degree of conceptualisation		
1. Scope. Context	Conditions and constraints; Contextualisation		
1. Scope. Measur. area	Conditions and constraints; Type of flows		
2. What features are considered ?			
3. What is a KPI measured for?			
4. KPI framework		KPI modeling. Framework	
4. KPI model	Origin of model	KPI modeling. Model	
4. KPI specification		KPI calculating. Code, Expression	
5. Clear and accurate syntax and semantics			Clear and accurate syntax and semantics
5. Expressiveness			
5. Evol. Modification			
5. Evolution. Traceability			
5. Evol. Propagation			
5. Understandability			Understandability
5. Standards support			
5. Acceptability			
5. Tech. Tool support			Proficiency in computational tractability
5. Tech. Code features			Extensibility
5. Tech. Reasoning functional.			
5. Empirically evaluated			
5. Customization			