KPIs in Operations Management: extending the ISO22400 standard scope

D'Orazio L.*, Schiraldi M.M.*, Varisco M.*

** Department of Enterprise Engineering, University of Rome "Tor Vergata", Via del Politecnico 1 - Rome – Italy (lorenzo.d.orazio@uniroma2.it; schiraldi@uniroma2.it; martina.varisco@uniroma2.it)*

Abstract: recently, the International Organization for Standardization published the ISO22400 standard, offering a set of key performance indicators (KPIs) for manufacturing operation management. This set is declared to be specifically referred to production execution. However, the standard includes either tactical indicators and operative ones. Moreover, production planning indicators are currently not taken into consideration, neither in ISO22400 not in other standards. Through an extensive literature review, this paper aims at investigating manufacturing operations management indicators and finding possible connections with ISO22400 standard, while identifying eventual needs for integration at tactical level. A framework for operations management KPIs is proposed and used to classify 778 indicators identified among scientific papers, white papers, reports and international standards. This lead to considerations on ISO22400 completeness and coherence; moreover, this classification can represent a reference for future standards formalization.

Keywords: Performance Management Systems, KPI, ISO22400, manufacturing, operations management

1. Introduction

Due to increasing complexity of industrial systems and of the competitive global context, a complete and transparent vision of manufacturing companies' processes plays a vital role in obtaining an alignment between pre-established objectives and performance. While the idea of measuring the production system performance is as old as the production system itself, research studies started massively focusing on identifying those key performance indicators (KPI) whose monitoring and controlling enable the achievement of strategic goals in manufacturing companies since late '90. Indeed, literature review can be divided into a generic class addressing performance measurement systems, and more operative insights devoted to the definition of measurement operative criteria defining key performance indicators.

1.1. Literature on performance measurement systems

The existing Performance Measurement Systems (PMSs) today are the result of an evolution over time. Originally, literature showed a substantial uniformity of views on the fact that performance measures must derive from a strategical view (Mintzberg, 1982; Fortuin, 1988; Sink, 1989; Maskell, 1989; D.P Keegan, 1989; J.R. Dixon, 1990; Bitton, 1990, Goold, 1991; R.L. Lynch, 1991; G. Azzone, 1991; R.S. Kaplan, 1992), as there are numerous authors who agree that the measures to be developed must possess a certain set of essential characteristics (Hall, 1983; Globerson, 1985; Lea, 1989; Crawford, 1990; House, 1991; Beamon, 1999). Regarding the prerequisites of the measurement criteria, some guidelines have been drawn, for example, by Globerson (Globerson, 1985) and Maskell (Maskell, 1989): Globerson declares that such criteria must derive from the objectives of the company, must be comparable, have a well-specified purpose, of the modalities of data collection defined in a univocal manner; Maskell offers some principles of designing a valid performance measurement system. The phases composing the measurement object determination process are defined in early literature (Keegan, Eiler, & Jones, 1989), while Wisner proposed a more detailed process (Wisner & S., 1991). Maskell (Maskell, 1991) put in evidence that, while financial ratios are important for strategic decisions and for publishing external results, daily control of production and distribution operations is better managed with non-financial measures. Many examples of structure with those characteristics considered essentials in literature have been found: an analysis of the literature reveals that the main deficiency found in today's performance measurement systems is their one-dimensional focus: the proposed solution is the use of a structured and balanced indicator system. Kaplan and Norton introduce an evaluation system for the cataloguing of this balanced set of indicators, which is called Balance Scorecard (Kaplan & Norton, 1992). Neely (Neely, 1997) proposes a structure for the definition of a measure articulated in ten points. De Toni (A. De Toni, 2001) identifies five types of PMS models in literature: (i) Strictly hierarchical models, characterized by cost and non-cost performance (Gold, 1985; C. Berliner, 1988; A. Lockamy, 1994; Partovi, 1994; Rangone, 1996). The first proposed model of this type was that of Gold, which connected productivity and ROI; (ii) Balanced scorecard or tableaux de bord models, where different performances are considered independently; these performances correspond to different perspectives (which remain effectively separate and the links between them are defined only in general) of analysis, financial, internal processes, customers and growth perspective (Maskell, 1991; R.S Kaplan, 1992; Brown, 1996; R.S Kaplan, 1996); (iii) "Frustum" type models, characterized by the synthesis of low-level measures in aggregated indicators, but not aimed at translating non-cost performance into financial performance; in fact, the economic and financial measures are usually kept separate from those relating to consumer satisfaction (R.L. Lynch, 1991; Hronec, 1993); (iv) Models that distinguish internal and external performances.

External performances are those perceived directly by consumers (E. Bartezzaghi, 1989; P.T. Bolwijn, 1990; Johnson, 1990); (v) Models related to the value chain; these models also consider the internal relationship between customer/supplier (D.S. Sink, 1989; B. Moseng, 1993), as for example VCOR standard (Supply Chain Council, 2007). This classification does not include those PMS models focused on operations management and the related more recent contribution in literature. This paper specifically focuses on the indicators in this specific field, aiming at proposing a framework for classifying them.

1.2. Literature on key performance indicators

Going deeper in the structure of a PMS, KPIs are found to define the measurement metrics to operatively lead performance improvements: "When you can measure what are speaking about and measure it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of meagre and unsatisfactory kind." (Arora, 2015). McClellan (McClellan, 1997) specifies the impact of a KPI structure on short and long-term goals for a manufacturing company. According to Parmenter (Parmenter, 2010), there are three types of performance measures: (i) Key result indicators (KRIs) tell you how you have done in a perspective; (ii) Performance indicators (PIs) tell you what to do; (iii) KPIs tell you what to do to increase performance dramatically. Many performance measures used by organizations are thus an inappropriate mix of these three types. The selection of the right number of KPIs is a fundamental aspect for companies (Liebetruth, 2006; Horvàth, 2009). It is not effective to use too many KPIs, as their excessive number could lead to incorrect decisions and incorrect interpretation of the KPIs (Bauer, 2005). In literature there is not an ideal number of KPIs to use, some sources suggest a number that varies between 10 and 15 (VDI, 1986), while others do not give restrictions (Carlucci, 2010).Kaplan and Norton do not recommend more than 20 KPIs, Hope and Fraser (Hope, 2003) suggest less than 10 KPIs, Parmenter (Parmenter, 2010) suggests the 10/80/10 rule as a guide. However, there are several levels of performance breakdown, mostly three, and specifically refer to a strategic level, a tactical level and an operational level. As we move from the strategic to the operational, the detail level of the indicators increases, but the intensity with which that indicator influences the total performance decreases. Turban and Aronson (Turban, 1998) affirm that the difference between these three hierarchical levels lies in the time scale that every decision requires and at the same time in the nature of the decisions themselves. According to Rushton and Oxley (Rushton, 1989) such a hierarchy is based on the time horizon in which different activities are carried out and on their influence on different levels of management. Furthermore, according to Marr, strategic measures are more focused on monitoring progress in order to reach new and better "destinations", and moreover they are not measures that change very often. (Marr, 2010). Lohman (C. Lohman, 2003) defines the selection of right KPIs as an essential requirement for a manufacturing company. Some of these metrics are generals, other related to the specific production process. In the formalization of a production KPI based on data, parameters and objectives, four dimensions must be defined (Veleva and Ellenbecker, 2001): (a) Unit of measurement (b) Type of measurement (c) Period of measurement (d) Boundaries. Bennett (Bennet, 1999), develops a model for deriving process indicators and Rakar (Rakar, 2004) propose a 8 steps closed loop model for defining and measuring production key performance indicators. Rakar offers also a KPIs categorization in which production KPIs are divided in three levels based on their importance for the company.

2. Lacks in literature and ISO 22400 contribution

The methodology for the definition of KPIs and dashboards of indicators have been mainly analysed in reference to business processes, while in the area relating to the production process significant deficiencies in the definitions are still found today. This is due to the fact that the organizational variety of the production systems, the interdisciplinarity and complexity of the operations, as well as the necessary conciliation of different strategic, tactical and operative objectives, make it difficult to define a reference structure for the formalization of a unique set of KPIs for a generic manufacturing context as well as a comprehensive framework to classify them. Despite the effort of Schick (Schick, 2007), who attempted to formalize a taxonomy, the analysis of most recent literature highlights the lack of a defined and integrated classification for quality performance measures, production logistics and maintenance (Juuso, 2013; Kumar, 2013).

We analysed 533 scientific contributions from the main scientific search engine with "KPI" and "manufacturing" keywords, since 1982; from this first set, 182 have been identified as being focused on performance measurement based on the abstract; finally, among these, 46 articles were explicitly proposing some kind of KPI set for manufacturing operations and have been selected and thoroughly analysed. The KPIs here listed have been inserted in a database which constitutes the base of the analyses described in this paper. The list of selected contribution (II selection) is reported in Annex.

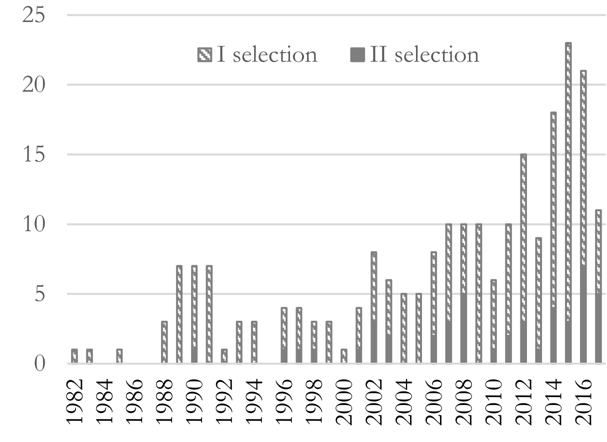

Figure 1: time distribution of literature contributions

Relying on this literature review, we can confirm a lack in the definition of a KPI classification framework, as well as a reference set of manufacturing related KPIs. Among those found, many indicators refer to aspects related to quality, production logistics and maintenance. However, they are almost always the most adopted at the system level and there are no structures with multiple categories and levels in which a certain KPI can fall, useful to formalize the relations between KPIs of different levels and the relations between KPIs belonging to the same level.

Kang (Kang, 2016) proposes a structure consisting of three hierarchical levels, each of which is associated with a particular element: the so-called support elements, the basic KPIs and complete KPIs. The latter are calculated from the former, the actual measurements (volumes or production times, etc.). One of the main obstacles in the definition of a well-defined set of KPIs for Manufacturing, is indeed the absence of a structure that allows to delineate the spatial, temporal boundaries to which the KPIs must be referred. The result of this lack is the presence in the literature of indicators of various types (referred to times, quantities, percentages) collected under the common name of KPIs. In addition, the absence of a hierarchical subdivision makes it almost impossible to establish which indicators should represent direct measures and which are instead calculated from the measures themselves. The hierarchical discrimination organized by levels of the company that can be identified in the literature is presented below.

Rakar (Rakar, 2004) proposes a structure represented as a hierarchical pyramid formed by three levels. The base corresponds to the so-called process level, which is the actual physical production process, followed by the production level and the business level as the top of the pyramid. A similar structure is presented by Lee (Lee, 2012), in which it is possible to identify: the strategic level, that includes long-term planning such as make or buy decisions; the tactical level that identifies medium-term actions, carried out on a weekly or monthly basis; the operating level to which daily management activities (daily scheduling) and shop floor control refer to. An example of a KPIs system based on this hierarchy (Liu, 2015) consists of a division into three groupings of KPIs: (i) enterprise-level KPIs, resulting from the analysis of critical success factors for the company's strategy; (ii) department-level KPIs, deriving from the decomposition of the enterprise level KPIs based on departmental responsibilities and specific business activities; (iii) Individual-level KPIs, which derive from the decomposition of department-level KPIs on the basis of individual responsibilities.

The comprehensive work of the Supply Chain Management Operational Reference model (APICS, 2010) introducing 520 KPIs in supply chain management describes a structure divided in five areas: Plan, Make, Source, Deliver, Return, introducing the interdependencies of the different indicators but without showing any hierarchical approach. Recently, the Logistic Maturity Model (Battista, 2010) describing 31 KPIs on supply chain and logistics management three levels of connection are defined among KPIs creating a sort of KPI network. On the manufacturing operations management side, the most significant contribution in defining a hierarchical structure in which KPIs can be framed is offered by the IEC 62264 standard, which has been used as a base for the proposed framework.

2.1. A functional hierarchy supporting KPI framework

IEC 62264 is an international standard for the integration of company control systems and is based on the ANSI/ISA-95 standard. It has been designed to be applied in all types of industries and processes, be they batch, repetitive or continuous. It introduces a functional hierarchy model including: business planning and logistics, manufacturing operations management, and batch, continuous or discrete, control. These levels provide different functions and work in different timeframes. The interface addressed in IEC 62264 shall be between Level 4 and Level 3 of the hierarchy model.

- Level 0: defines the actual physical processes, usually the manufacturing or production process
- Level 1: defines the activities involved in sensing and manipulating the physical processes. Level 1 typically operates on time frames of seconds and faster.
- Level 2: defines the activities of monitoring and controlling the physical processes, either manual or automated. Level 2 typically operates on time frames of hours, minutes, seconds and sub-seconds.
- Level 3: defines the activities of the work flow to produce the desired products. It includes the activities of maintaining records and coordinating the processes. Level 3 typically operates on time frames of days, shifts, hours, minutes and seconds.
- Level 4: defines the business-related activities needed to manage a manufacturing organization. Manufacturing-related activities include establishing the basic plant schedule (such as material use, delivery and shipping), determining inventory levels and making sure that materials are delivered on time to the right place for production. Level 4 typically operates on time frames of months, weeks and days.

IEC62264 also provides a list of activities typically included in Level 3 and Level 4. Relying on this hierarchical division, ISO 22400 provides a set of KPI for manufacturing which nowadays the most complete and organic one.

2.2. ISO 22400 contribution

The International Standard Organization (ISO) has developed the ISO 22400 international standard, which defines a set of KPIs for manufacturing operations management and offers clear definitions for the calculation of KPIs. The ISO 22400 standard is part of the Automation system and integration and in particular deals with the definition of KPI for Manufacturing Operations Management. Specifically, reference is made to Manufacturing Operations Management (MOM) as to Level 3 defined in the IEC 62264 standard, which therefore represents the scope of definition of the ISO 22400 standard and constitutes the perimeter necessary to frame the KPIs that will be defined.

KPIs presented in ISO 22400 are a total of 34 and have been identified as examples of the KPIs mostly used by companies for measuring the performance of manufacturing systems. For each KPI the standard identifies a calculation formula (to derive the numerical value of the KPI) that can be composed of an aggregation of functions, measurements or other KPIs. For each of the KPIs chosen, a range of allowable values is defined, the timing with which it must be measured. The contribution offered by the ISO 22400 standard in terms of formalization of KPIs for manufacturing is therefore not limited to the definition of a set of reference KPIs (the lack of which was already mentioned), but also of the elements detected by the physical process from which the KPIs are calculated.

3. The proposed framework model

As mentioned, literature lacks a classification framework categorizing and comparing existing KPIs. Analogously, it is difficult to verify the completeness of ISO 22400. Therefore, here we propose a categorization of KPIs related to manufacturing activities and, more generally, to all activities related to production management. The purpose of this subdivision is to highlight possible discrepancies between the areas defined in the reference standards, or the need to integrate sets of indicators, in order to provide an organic and complete framework aimed at harmonizing existing literature and standards defined by international committees. The criteria for subdividing the indicators derived from literature are inherited from the existing international standards, with the aim of making the categorization as less arbitrary as possible. After the definition of the classification framework, a total number of 778 KPIs, originating from 51 sources (listed in Annex A) among scientific papers, white papers, reports and international standards, have been classified. The proposed framework is designed to analyse the existing literature by discriminating between IEC62264 Level 3 and Level 4 KPIs, while verifying the consistency with ISO22400 standard. Furthermore, the framework proposes a set of KPIs classified as Level 4 indicators, verifying their completeness as well.

3.1. Classification Criteria

Each classification criterion is analysed by examining the sources from which it is inherited: thus, as said, a first classification criterion is based on the hierarchical categorization carried out in IEC 62264 between Level 3 and Level 4: Level 3 and Level 4 describe activities related to production executing and production planning respectively, for which reference time frames are specified. For each indicator, information has been collected that allows it to be classified as Level 3 or Level 4 KPIs, referring to the time window in which the activities of each level are defined for each indicator, we analysed which was the adequate monitoring frequency. The KPIs to be monitored on an hourly basis fall within the Time Bucket defined as Level 3, those to be monitored on a weekly or monthly basis in the Time Bucket defined as Level 4. 68 Level 3 KPIs and 96 Level 4 KPIs can be found in scientific papers, while 118 Level 3 KPIs and 497 Level 4 KPIs are found in other different sources.

Second classification criterion is the correspondence of the KPIs to one of the activities described among the IEC62264 Level Activities. However, given that each Level includes multiple activities, it was decided to group them into Production, Inventory, Maintenance or Quality groups according to MESA MOM Capability Maturity Model (Brandl, 2016). Activity Group "None" includes KPIs with no reference to any of these four.

The third classification criterion is the production process phase (Area) to which the KPIs refer: Make, Plan, Source, Deliver areas, inherited from SCOR. Since these areas are related to the entire Supply Chain management, and because Level 3 and Level 4 definitions refer respectively to production execution and planning, reasonably some areas do no find correspondence with the previously defined Level Activity Groups.

Finally, the fourth classification differentiates the KPIs by "Type": many indicators referred to aspects which are not included in the Level Activities (e.g. risk management, cost measurement, or supporting activities) that is, activities not directly connected to production management. Table 1 shows the 778 KPIs classification.

Table 1: 778 KPIs in the proposed framework

		LEV 3				LEV 4			
		MAKE	PLAN	SOUR	DELI	MAKE	PLAN	SOUR	DELI
CORE	PROD	67	15	1	-	22	48	7	3
	INVE	9	-	2	1	4	12	3	9
	MAIN	12	4	-	-	5	12	1	-
	QUAL	29	2	-	-	5	1	5	12
	NONE	-	3	5	25	10	22	27	94
COST	PROD	1	-	-	-	12	24	6	-
	INVE	-	-	-	-	-	3	1	-
	MAIN	-	-	-	-	-	3	-	-
	QUAL	-	-	-	-	3	-	-	-
	NONE	7	-	-	2	34	25	30	53
RISK	PROD	-	-	-	-	-	-	-	-
	INVE	-	-	-	-	-	-	-	-
	MAIN	-	-	-	-	-	-	-	-
	QUAL	-	-	-	-	-	-	-	-
	NONE	-	-	-	-	21	11	17	18
SUPP	PROD	-	-	-	-	-	-	-	-
	INVE	-	-	-	-	-	-	-	-
	MAIN	-	-	-	-	-	-	-	-
	QUAL	-	-	-	-	-	-	-	-
	NONE	1	-	-	-	9	2	4	14
TOTAL		778 KPIs							

4. Discussion

The analyses carried out on the database designed with the classification criteria illustrated above have made it possible to reach conclusions regarding the completeness of the ISO 22400 standard within its scope; moreover, a set of indicators has been identified that can represent a useful example in the drafting of a standard for the definition of a set of KPIs for Level 4. Results achieved are then exposed, highlighting shortcomings and possible additions, taking into consideration Level 3 and Level 4 KPIs separately.

4.1. Discussion on Level 3 KPIs

Regarding Level 3 indicators, the division into Areas put in evidence that the majority of these KPIs can be classified as Area Make indicators. KPIs related to other Areas however, aim at measuring the performance of activities that can be considered as an extension of the manufacturing process, such as for example packaging activities. The division into Areas therefore confirms that considering a time horizon characteristic of Level 3 (minutes, hours, days), only those indicators related to production execution are reported in literature. The completeness of the KPIs introduced by ISO 22400 with respect to all the activities of Level 3 was detailed considering all the indicators of ISO 22400, comparing them with the corresponding Level activities, and integrating this analysis with the comparison with all the other Level 3 indicators taken from literature.

We highlight a coverage by the ISO 22400 KPIs of all activities related to Maintenance Operations, and a complete uniformity of the KPIs present in the literature with those introduced by ISO 22400. Also, as regards the activities related to Inventory Management, ISO 22400 introduces indicators dedicated to monitoring the detailed activities in IEC 62264. The activities related to the Quality Operations Management are well represented by the KPIs introduced by ISO 22400 (completely similar and more complete and structured than those KPIs found in the literature).

Regarding the activities related to Production Operations Management, the high number of KPIs introduced by ISO 22400 highlights the significance of the contribution provided in terms of standardization, especially if these indicators are compared with those present in literature: many of the latter are in fact attributable to KPIs introduced in ISO 22400 or alternatively to elements composing them, such as Time Elements or Logistical Elements; this fact underlines the completeness of what is defined in ISO 22400, which offers a subdivision of the structured elements so as to be able to derive KPIs from elements. The coverage of Level 3 activities related to Production Operations Management is complete except for the definition and modification of the production schedule area to offset any production interruptions; in fact, there are no KPIs directly aimed at managing this activity, although many of the KPIs defined in ISO 22400 represent the information necessary for rescheduling production. It should be noted, however, that the definition and modification of the production schedule is an activity more closely related to production planning than to production execution; although it therefore appears among the activities of Level 3, it can also be considered a Level 4 activity (it is not by chance that it is also included in Level 4 activities).

Finally, it is emphasized that within IEC62264 Level 3, some activities include the management and optimization of production costs in the area, and reporting activities on variable production costs are also mentioned. ISO 22400, however, does not introduce any indicators aimed at measuring production costs. An example of possible integration of the standard in this sense, is offered by many of the indicators found in the literature, all but linked by the fact of being referable to both Level 3 and Level 4. Most of the Level 4 indicators detected by SCOR are related to the measurement of costs, however, it's also necessary to define a set of Level 3 indicators related to cost reporting activities, as required in the IEC62264 Level 3 activities.

4.2. Discussion on Level 4 KPIs

The analysis of the literature for the identification of Level 4 indicators led to the determination of a high number of indicators detected above all by reference models for the measurement of Supply Chain performances, such as SCOR, LMM and VCOR. A great number of KPIs are connected to the measurement of costs, risks and performance of activities linked to the Deliver and Source areas, as well as Make and Plan. Only part of these, however, are interesting for the purposes of the present analysis since, as mentioned, reference is made to the activities specified in Level 4 defined in IEC 62264, so attention will be focused on KPIs related to activities connected to production planning. Therefore, indicators related to the measurement of costs and risks were excluded from the analysis. The classification by type therefore allowed to exclude a consistent set of indicators. Core KPIs were then studied with reference to Level 4 activities, as previously done for Level 3 activities.

A set of the selected indicators does not appear to be related to any of the activities defined in IEC 62264, but this fact is in agreement with the production planning activities detailed in Level 4: these KPIs are in fact mainly related to the Deliver and Source areas, not included in Level 4 activities. The remaining Core KPIs were divided into the four Level Activity Groups, and analysed to highlight any gaps between what defined in IEC 62264 and the findings of the selected indicators. Differently from Level 3, however, it was not possible to compare with any standard, so the shortcomings with respect to the activities defined in IEC 62264 were simply highlighted.

Regarding Level 4 activities related to the management of Inventory Operations, numerous KPIs were found, which share the lack of a relational link between Time elements. In drafting a standard similar to ISO 22400 but defined for Level 4 activities, the KPIs detected can represent a useful example for the management and monitoring of Inventory activities, but the necessary preliminary definition of temporal metrics should be considered to allow these KPIs to be integrated with each other. We also point out the lack of indicators directly aimed at determining the optimal level of inventory, as required by the Level 4 activities, the definition of which, however, would be possible starting from the analysed KPIs, with the appropriate already described definition of structured time metrics. The activities related to Quality Operations for Level 4 are widely represented among the indicators detected, but there are no KPIs referring specifically to information on quality control requested by the client, as detailed in the Level 4 activities. However, the lack of specificity of the description of this activity provided by IEC 62264 makes it difficult to identify indicators specifically designed for its management. With regard to the activities related to Level 4 Maintenance Operations, there is a complete coverage of the Level 4 activities defined in IEC 62264, and a substantial similarity between the identified KPIs and those defined in ISO 22400, but with reference to a different time horizon.

Finally, as regards the activities related to Production Operations Management and in particular to the production planning (given the Level 4 activities presented in IEC 62264), the highest number of Level 4 KPIs are found in this categorization, most of which belonging to the Make and Plan Areas. Many indicators among these have been highlighted that can represent a significant informative contribution in the definition of the production schedule. These KPIs, since the modification of the production schedule is a theme that also concerns Level 3 activities and for which no KPIs have been detected, can represent an example of what is currently monitored to provide a contribution to the definition of a more complete and structured Level 3 indicator set (with regards to the production schedule change).

5. Conclusions

Literature review highlighted the lack of a complete and integrated reference framework on KPIs for production management and, specifically, for manufacturing. The great heterogeneity of the indicators in literature confirms the need to design a structure that allows their comparison as well as the selection of the most representative according to the required use. Taking cue from IEC62264, SCOR and MESA MOM, a KPI classification framework is here proposed, considering the time frame of their measurement, the activity and the area to which they refer as well as their type.

Through this classification framework, it was possible to verify a substantial compliance of the KPIs defined in ISO22400 with the IEC62264 Level 3 activities along with its relative completeness: ISO22400 KPIs collect much of the information content offered by all the other indicators present in the literature but show some lacks in those areas going beyond production execution and at the border with production planning. In this direction, some of the cited indicators may represent optimal candidates for an eventual ISO22400 extension, to include all the activities defined in IEC 62264. Analogously, the Level 4 indicators classification can lead the way towards the design of a new standard for KPIs in production planning. This would anyway require the formalization of a structure of links between KPIs and basic elements, similarly to what is reported in ISO 22400, which can represent a next challenge.

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Annex A

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Selected contributions list