Proposal for a classification of ISO22400 KPIs for Manufacturing Operations Management

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Abstract: The ISO22400 standard defines key performance indicators for manufacturing operation management. Its visionary goal is to be applicable to all industry types, regardless the production methodology and the process configuration. Pursuing this objective, a challenging trade-off between generality and specificity in the definitions must be found. In the cited standard, the former approach has been preferred: thus, several indicators seem too vaguely defined and result to be difficulty usable in real contexts. Our aim is to refine the ISO22400 standard definitions and in this paper, by means of a designed classification method combined with the explicit and implicit existing information, the indicators are analysed according to their specific initial application context. Afterward, context extensions are proposed to overcome the recognised shortcomings and to better support performance measurement. In this step on the road to the improvement of the ISO standard, we managed to refer each indicator to work orders, production orders, work units, to the entire process, and to possible combination of these. This information is crucial to proceed towards a better interpretation of the standard and, thus, its diffusion in the real world.

Keywords: **ISO22400, KPIs, performance management, manufacturing operation management**

1. Introduction

The ambitious aim of ISO22400 standard *KPIs for manufacturing operation management* is to support performance management in all the industry and process types, regardless the specific characteristic. Thus, a set of KPIs and basic elements allowing the KPIs computation are defined. Chasing the wide applicability, the standard seems to lack of the clear information to define the object of performance. In this paper, by the use of a designed classification model, an analysis was performed to identify the context of each ISO22400 performance measures. After a brief review on performance measurement systems in manufacturing, the ISO22400 is introduced. Next, the analysis procedure is described: first, the classification model is recalled, then how the initial contexts were obtained is explained; finally, the analysis leading to the context extension is shown. The obtained results are reported and then discussed in the conclusions.

2. Literature

KPIs are essential for process improvement: selecting the right KPIs (Neely et al., 2005) and the right number of KPIs (Horvàth, 2009), is a challenge also in manufacturing environments. KPIs should reflect the manufacturing goals and support the performance improvements (Muchiri et al.,2009). In their review, Frutuoso et al. (2011) underline how KPIs should be simple and clear to allow to rapidly identify what and how that is being measured. Moreover, KPIs in manufacturing systems are not independent but have mutual intrinsic relationships. Grouping indicators into categories and levels, with well-defined connections, can be supportive (Ahmad & Dhafr, 2002). Several KPI classifications have been proposed in literature: among these, De Toni and Tonchia (2001) provide a multilevel KPIs categorization; Rakar et al. (2004) divide manufacturing KPIs in three levels based on the maturity level of performance management; Hon (2015) reviews the manufacturing performance measurement evolution by using a framework based on five metrics and levels, going from the workstation to the entire manufacturing system; Stricker et al. (2016) use linear programming to identify a holistic set of KPIs. They select a sub set out of the 130 identified KPIs and underlines how those can be related to orders, work units, process centres, or to the whole production system. Moreover, they divide KPIs in basics, hence that can be measured on the shop floor, and the ones than can be computed by using mathematical links between the basic KPIs.

3. ISO22400

KPIs have recently drawn the attention of International Standards Organization. Indeed, ISO22400 has been first published in 2014. The standard currently includes the part 1, part 2, an amendment to part 2 and a technical report. The performance indicator for manufacturing operation management are introduced in part 2. The KPIs are computed starting from basic metrics, called elements. For almost all the elements a definition is provided. Moreover, schemes representing the relationship among the time elements for a work unit and for a production order are provided. Each KPI structure is reported in a synoptic table where the formula and a description is presented.

Moreover, the scope, the unit of measures, the range and the trend, the frequency, the audience, the production methodology of each KPI are also reported.

However, the information contained in the synoptic tables seems to be sometimes vague, imprecise, incomplete, or inconsistent. An example is represented by the *inventory turn* KPI (see ISO22400:2, table 25, page 28): this is defined as the ratio between *throughput* and *average inventory*. First, average inventory is not introduced nor formally defined in the standard. Furthermore, *inventory turns* KPI is reported to be only applicable in *continuous production* contexts, whether *throughput* is defined as applicable in *discrete* and *batch production* contexts only. Therefore, readers may face difficulties in deeply understanding the ISO22400 standard, thus limiting its applicability in real cases.

4. Classifying the ISO22400 indicators

Despite its shortcomings, the ISO22400 represents a valuable guideline for performance management in manufacturing. However, we believe that enhancement opportunities are present through specific refinements aiming at supporting the users in the standard application. A first step in this direction can be found in Varisco et al. (2018) where a proposal for a theoretical classification model of ISO22400 elements and KPIs is outlined, as a part of a broader improvement process.

The present work takes cue from this classification model, which is recalled in the following section. The further step now needed is to match the theoretical model with the ISO22400 original definitions and thus highlight the applicability of each of the elements and indicators proposed in the standard. Then, we also propose some extensions of each element and KPIs applicability beyond what the standard originally indicates.

Despite the work has been done on 67 elements and 41 KPIs definitions in the ISO22400 standard, in this paper only some examples are shown to describe the used approach, due to space constraints. The complete results are discussed and summarized in table format.

4.1 The classification model

The ISO22400 synoptic tables already contain a classification scheme for all the KPIs: indeed, the standard defines a *KPI scope* as “the element for which the KPI is relevant” and possible KPI scopes result to be: product, equipment, production order, plant, work unit, work centre, area, production order sequence, worker, workgroup, characteristic, series of measurements, stock, defect type, time period. Besides the fact that “element” in ISO22400 has a specific meaning, which is not what is intended in the cited definition of scope (“a relevant measurement for use in the formula of a KPI”), this list seems also to mix several different concepts, thus its usefulness is uncertain. For example, it is not immediate to understand why Overall Equipment Effectiveness (OEE) KPI scopes include “defect type”.

Differently, the classification in Varisco et al (2018), recalled in Figure 1, aims to define “what a KPI is related to”, thus indicating the subjects of the performance measurement. Combinations of these subjects have been defined as “classes” that are not mutually exclusive.

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="5">Work Order (WO) or Production order (PO)</td></tr>
<tr><td colspan="3">WO</td><td colspan="2">PO</td></tr>
<tr><td>Single</td><td colspan="2">Multiple</td><td>Single</td><td>Multiple</td></tr>
<tr><td rowspan="3">Work Unit - WU</td><td rowspan="2">Single</td><td rowspan="2">WU-WO</td><td>Part of a single PO</td><td>Part of different POs</td><td rowspan="2">WU-PO</td><td rowspan="2">WU-POs (or WU-WOs)</td></tr>
<tr><td>WU-PO</td><td>WU-POs (or WU-WOs)</td></tr>
<tr><td>Multiple</td><td>Not Admissible</td><td colspan="2">WUs-POs</td><td>WUs-PO</td><td>WUs-POs</td></tr>
</table>

Figure 1: Classification model

The five classes are defined as follows:

- WU-WO class refers to the measurement of the activities identified by a single work order (WO) on a single work unit (WU);
- WU-PO class refers to the measurement of the activities identified by a single production order (PO) on a single work unit;
- WU-POs class refers to the measurement of the activities identified by all the production orders on a single work unit;
- WUs-PO class refers to the measurement of the activities identified by a single production order on all the work units included in the production order path;
- WUs-POs class refers to the measurement of the activities identified by all the production orders on all the work units.

4.2 Elements and KPIs classification

At first, an initial classification of the elements is obtained applying the proposed model to the definitions included in the ISO 22400 standard. Specifically, each one can be explicitly or implicitly classifiable: Explicitly (E) means that the class can be detected by interpreting the existing definition or other info which are clearly stated in the standard (e.g. time models). Otherwise, a selected element can be then implicitly (I) classified by using an evident relationship with other explicitly classified elements. Differently, an element can also be non-classifiable (NC) in case of lack or inconsistency of the existing information, or its classification can be derived (D) by further investigations on the intrinsic meaning of the element.

For example:

- ISO 22400 defines the produced quantity (PQ) as *the quantity that a work unit has produced in relation to a production order*. Thus, it is explicitly stated that the produced quantity is referred to a production order and a work unit. Hence, PQ has been explicitly (E) classified as a WU-PO element.
- ISO22400 defines the good quantity (GQ) as *the produced quantity that meets quality requirements*. The definition explicitly said that GQ is part of PQ. Because PQ is a WU-PO element, it is implicitly (I) stated that GQ belongs to the same class as well.
- ISO22400 defines the planned run-time per-item (PRI) as *the planned time for producing one quantity unit*. This definition does not explicitly relate to any class; however, despite it is not specified in the standard, *the planned time for producing one quantity unit* is referred to the production speed of a single work order on a single work unit. Hence, PRI WU-WO classification is derived (D) from secondary considerations.
- ISO22400 defines the inspected part (IP) as *the count of individual identifiable parts, e.g. by serialization, which was tested against the quality requirements*. Moreover, a note states that *in discrete manufacturing, a part is typically a single produced item. In batch manufacturing, a party refers to a specified material lot*. The information provided on this element does not allow to uniquely find a class. Hence, IP results to be non-classifiable (NC).

ISO 22400 standard also includes, among the elements, indicated as quality elements, some mathematical concepts (e.g. arithmetic average, standard deviation, variance etc.) as well as basic indicators (e.g. lower specification limit, upper specification limit, etc.) which have been excluded from the analysis, as well as the related KPIs. A first classification is proposed as well for KPIs also, based on the standard definitions and on the analysis of the elements included in the KPI formula. Here, similarly to the elements, a KPI can be explicitly (E), implicitly (I), derived (D) or non-classifiable (NC) as well.

For example:

- ISO 22400 defines the equipment load ratio (ELR) as *the produced quantity (*PQ*) in relation to the equipment production capacity (*EPC*)*. Hence, the KPI explicitly (E) relates to a work unit or to an entire production path, thus it's a WU-POs or WUs-PO indicator.
- ISO 22400 defines the quality ratio (QR) as *the relationship between the good quantity (*GQ*) and the produced quantity (*PQ*)*. GQ and PQ have been identified as WU-PO elements, hence, QR can also be implicitly (I) classified in as a WU-PO KPI.
- ISO 22400 defines the production process ratio (PPR) as *the relationship between the actual production time* (APT) *of all work units and work centres involved in a production order, and the whole throughput time of a production order which is the actual order execution time* (AOET). Hence, this results to be ΣAPT/AOET where ΣAPT is *the sum of the* APT *of all work units and work centres involved in a production order*. AOET is a WUs-PO element, while APT is both a WU-WO and a WU-POs element. But, since the definition indicates the elements to be summed, APT must be intended as WU-WO; therefore, PPR is related to the production order and, hence, it is derived (D) as a WUs-PO indicator.
- ISO 22400 defines effectiveness (EFV) as *the relationship between the planned target cycle and the actual cycle expressed as the planned runtime per item* (PRI) *multiplied by the produced quantity* (PQ) *divided by the actual production time* (APT). PQ is classified as WU-PO, PRI as WU-WO and APT is both a WU-WO and a WU-POs element. In this case the elements classification is not coherent. Hence, an inconsistency results in the formula indicated in the standard. Thus, the EFV cannot be classified (NC) without further analysis.

Next the opportunity to extend the applicability of an element or of a KPI in other classes than the ones initially defined by the ISO22400 is considered. Besides solving incoherencies – see for example the effectiveness definition shown among the example – some elements and KPIs need to be anyway referable to specific classes in order to support the real applicability of the standard.

Indeed, some of the KPIs introduced by the ISO22400 would not be computable since the elements used in their formulas are not homogeneous, i.e. not related to the same classes. In this paper no changes to the KPIs' formulas have been proposed, even though this would have been sometimes needed in order to adapt them to the extended contexts: indeed, in some cases, substituting the elements related to a context in the formula provided by the ISO22400 would not be sufficient to obtain a coherent formula of the KPI in the same context.

For example:

- ISO 22400 defines the throughput rate (ThR) as the *process performance in terms of produced quantity of an order (PQ) and the actual execution time of an order (*AOET*)*. The PQ has been originally classified as a WU-PO element while the AOET as a WUs-PO one. Hence, the ThR elements are inconsistent in its definition. However, the ThR definition explicitly refers PQ to an order execution, which is related to the WUs-PO class; hence, the ThR WUs-PO classification can be derived (D). This, in turn, pushes to extend PQ classification to WUs-PO also.
- As said before, according to the ISO 22400 standard, effectiveness (EFV) cannot be classified (NC) because the elements in its formula are defined in different classes and the KPI definition does not explicitly indicates the application context. However,

the effectiveness KPI is included in the Overall Equipment Effectiveness (OEE) indicator, which must be clearly referred to WU-POs class. Thus, effectiveness must be extended in this class also, in order to maintain coherency with its related OEE KPI.

5. Results

The designed classification model has allowed to identify the initial context of 91% elements among those cited in the ISO 22400 standard and not excluded by the analysis, and to identify possible extensions for 50% of them. Specifically, the initial classification for the elements resulted to be explicit (E) in 55% of the cases, implicit (I) in 19%, derived (D) in 17% while only 9% resulted to be non-classifiable. Detailed results about the classes of the elements are summarized in Figure 2

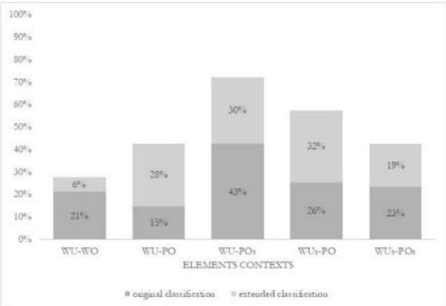

Figure 2: Elements classification results

In Table 1, elements are divided into the ISO 22400 categories: logistical, time and quality; the energy category has been added to include those new elements introduced in the 2017 amendment (AMD1) for energy KPIs.

Considering the KPIs, the designed classification model has allowed to identify the initial context of 61% elements among those cited in the ISO 22400 standard and not excluded by the analysis, and to identify possible extensions for 68% of them. Specifically, the initial classification for the KPIs resulted to be explicit (E) in 8% of the cases, implicit (I) in 42%, derived (D) in 11% while only 39% resulted to be non-classifiable. Results on the KPIs classes are synthesized in Figure 3.

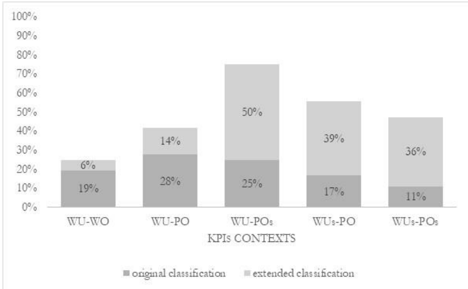

Figure 3: KPIs classification results

In

Table 2 KPIs are divided into logistical, time, quality, maintenance, mixed-production and mixed-energy categories. KPI acronyms have been introduced to facilitate reading.

Thanks to this classification, it is now possible to precisely identify the context each element and KPI is related to.

Table 1: Elements classification

Type	Acron	Name	Original class	Original class type	WU-WO	WU-PO	WU-POs	WUs-PO	WUs-POs
Logistical	PQ	produced quantity	WU-PO	E	Δ	❖	Δ	Δ	Δ
Logistical	SQ	scrap quantity	WU-PO	I		❖	Δ	Δ	Δ
Logistical	RQ	rework quantity	WU-PO	I		❖	Δ	Δ	Δ
Logistical	GQ	good quantity	WU-PO	I	Δ	❖	Δ	Δ	Δ
Logistical	POQ	planned order quantity	WU-PO	I		❖	Δ	Δ	Δ
Logistical	PSQ	planned scrap quantity	WU-PO	I		❖	Δ	Δ	Δ
Logistical	IGQ	integrated good quantity	WU-POs and WUs-POs	I				❖	❖
Logistical	EPC	equipment production capacity	WU-PO and WU-POs	I	Δ	Δ	❖	Δ	Δ
Logistical	CM	consumed material	WUs-PO and WUs-POs	E		Δ	Δ	Δ	❖
Logistical	RM	Raw materials	WUs-PO and WUs-POs	D				❖	❖
Logistical	RMI	Raw materials inventory	WUs-PO and WUs-POs	D				❖	❖
Logistical	CI	consumables inventory	WUs-PO and WUs-POs	E				❖	❖
Logistical	FGI	finished goods inventory	WUs-PO and WUs-POs	D				❖	❖
Logistical	AI	Average inventory	WUs-PO and WUs-POs	D				❖	❖
Logistical	PL	production loss	WUs-PO and WUs-POs	D		Δ	Δ	❖	❖
Logistical	OL	other loss	WUs-PO and WUs-POs	D				❖	❖
Logistical	STL	storage and transportation loss	WUs-PO and WUs-POs	D				❖	❖
time	ADET	actual unit delay time	WU-WO & WU-POs	E	❖	Δ	❖		
time	ADOT	actual unit downtime	WU-POs	E			❖		
time	AOET	actual order execution time	WUs-PO	E		Δ		❖	
time	APT	actual production time	WU-WO and WU-POs	E	❖	Δ	❖	Δ	
time	APWT	actual personnel work time	WUs-PO and WU-PO	E		❖	❖		
time	APAT	actual personnel attendance time	WUs-POs and WU-POs	E				❖	❖
time	AQT	actual queuing time	WU-WO	E	❖	Δ		Δ	
time	ATT	actual transport time	WU-WO	E	❖	Δ		Δ	

Type	Acron	Name	Original class	Original class type	WU-WO	WU-PO	WU-POs	WUs-PO	WUs-POs
time	AUBT	actual unit busy time	WU-WO and WU-POs	E	❖	∆	❖	∆	
time	AUPT	actual unit processing time	WU-WO and WU-POs	E	❖	∆	❖		
time	AUST	actual unit setup time	WU-WO and WU-POs	E	❖	∆	❖		
time	PBT	planned busy time	WU-POs	E			❖		
time	PDOT	Planned down time	WU-POs	E			❖		
time	PSDT	planned shut down	WU-POs	E			❖		
time	POET	planned order execution time	WUs-PO	E		∆		❖	
time	POT	planned operation time	WU-POs	E			❖		
time	PRI	planned run time per item	WU-WO	D	❖	∆	∆	∆	
time	PUST	planned unit setup time	WU-POs	E		∆	❖		
time	CMT	corrective maintenance time	WU-POs	E			❖		
time	FE	failure event	WU-POs	E			❖		
time	PMT	preventive maintenance time	WU-POs	E			❖		
time	TBF	operating time between failure	WU-POs	E			❖		
time	TTF	time to failure	WU-POs	E			❖		
time	TTR	time to repair	WU-POs	E			❖		
time	LT	loading time	Not defined	NC			∆		
time	OPT	operating time	Not defined	NC			∆		
time	NOT	net operating time	Not defined	NC			∆		
time	VOT	value added operating time	Not defined	NC			∆		
Energy	ADEC	Actual direct energy consumption	WU-WO and WU-POs	I	❖	∆	∆	∆	∆
Energy	PDEI	Planned direct energy consumption per item	WU-WO	I	❖	∆	❖	∆	∆

❖ Elements original classification, ∆ Elements extension

Table 2: KPIs classification

Type	Acron	Name	Original class	Initial class type	WU-WO	WU-PO	WU-POs	WUs-PO	WUs-POs
Logistical	QR	Quality ratio	WU-PO	I		❖	∆	∆	∆
Logistical	SR	Scrap ratio	WU-PO	I		❖	∆	∆	∆
Logistical	RR	Rework ratio	WU-PO	I		❖	∆	∆	∆
Logistical	FOFFR	Fall off ratio	WU-PO	I		❖	∆	∆	∆
Logistical	APSR	Actual to planned scrap ratio	WU-PO	I		❖	∆	∆	∆
Logistical	INVT	Inventory turns		NC				∆	∆
Logistical	FGR	Finished goods ratio		NC				∆	∆
Logistical	IGR	Integrated goods ratio	WUs-POs	I				∆	❖
Logistical	PLR	Production loss ratio	WUs-PO and WUs-POs	i		∆	∆	❖	❖
Logistical	STLR	Storage and transportation loss ratio	WUs-PO and WUs-POs	I				❖	❖
Logistical	OLR	Other loss ratio	WUs-PO and WUs-POs	I				❖	❖
Logistical	ELOADR	Equipment load ratio	WU-PO	I	∆	❖	∆	∆	∆
Time	WEFC	Worker efficiency		NC					
Time	AR	Allocation ratio	WUs-PO	D				❖	
Time	AEFC	Allocation Efficiency	WU-POs	D			❖		
Time	UEFC	Utilization efficiency	WU-WO and WU-POs	I	❖	∆	❖		
Time	AV	Availability	WU-POs	I			❖		
Time	AV (2)	Availability (2)		NC			∆		
Time	EFV	Effectiveness		NC			∆		
Time	SUPR	Setup Ratio	WU-WO and WU-POs	I	❖	∆	❖		
Time	TEFC	Technical efficiency	WU-WO and WU-POs	I	❖	∆	❖		
Time	PPR	Production process ratio	WUs-PO	D				❖	
Maintenance	MTBF	Mean operating time between failures	WU-POs	E			❖		
Maintenance	MTTF	Mean time to failure	WU-POs	E			❖		
Maintenance	MTTR	Mean time to repair	WU-POs	E			❖		
Maintenance	CORRMR	Corrective maintenance ratio	WU-POs	I			❖		
Mixed-Prod	THR	Throughput rate	WUs-PO	D				❖	∆
Mixed-Prod	PR	Performance ratio		NC			∆		
Mixed-Prod	OEE	Overall equipment effectiveness index		NC			∆		
Mixed-Prod	OEE (2)	Overall equipment effectiveness index (2)		NC			∆		
Mixed-Prod	NEE	Net equipment effectiveness index		NC			∆		
Mixed - Energy	DECE	Direct Energy Consumption Effectiv.		NC	❖	❖	∆	∆	∆
Mixed - Energy	DNECE	Direct Net Energy Consumption Effectiv.		NC	❖	❖	∆	∆	∆
Mixed - Energy	DEEFC	Direct Energy Efficiency		NC	❖	❖	∆	∆	∆
Mixed - Energy	DNEEFC	Direct Net Energy Efficiency		NC	❖	❖	∆	∆	∆
Mixed - Energy	CEC	Comprehensive energy consumption		NC	∆	∆	∆	∆	∆

❖ KPIs original classification, ∆ KPIs extension

6. Conclusions and further contributions

The ISO 22400 standard may represent an important guide to support performance measurement in manufacturing operation management. The standard has been conceived to be general enough in order to be applicable to a large range of cases. However, it often appears to be vague and much information is implicit or missing. The main contribution of this paper is clarifying the contexts of each indicators introduced in the ISO 22400. Thanks to this analysis and by using an appropriate classification method, we managed to refer each indicator to work orders, production orders, work units, to the entire process, and to possible combination of these.

This allows engineers and system designers to easily identify which data shall be collected on field to implement a performance management system compliant to ISO22400 standard. On the other hand, this classification allows manager to understand which KPIs can be currently computed with a given set of data. This is specifically useful in installing PMS software or when launching improvement projects in manufacturing operations management.

On the road to the improvement of the ISO standard, this step is crucial to proceed towards a better interpretation of the standard and, thus, its diffusion in the real world. Future work is being done to introduce subscript indices to each element and KPI, referring to work orders, work units and production orders, aiming at formally refining the computation formulas and allowing a better understanding of this potentially crucial body of knowledge.

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