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From production planning flows to manufacturing operation management KPIs: linking ISO18828 & ISO22400 standards

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Abstract: International standards are playing a key role in leading and shaping the smart manufacturing landscape. The integration and consistency among different standards is therefore essential to effectively support industrial automation evolution and to ensure their applicability. This paper focuses on the ISO18828 and ISO22400 standards, related to the production planning process and manufacturing, consequential phases in product lifecycle. In this paper the connections between the information related to production planning process (ISO18828) and the KPI main basic elements in manufacturing operation management (ISO22400) are analysed. The analysis aims at supporting the standards' users, underlining the aspects that should be taken into account in order to consolidate and improve the considered lifecycle phases.

Keywords: KPI; enterprise system engineering; operations management; production planning; performance evaluation; factory automation; manufacturing execution system;

1. INTRODUCTION

Key performance indicators (KPIs) are defined as a set of quantifiable and strategic measurements that reflect the critical success factors of a firm. The appropriate selection and better understanding of KPIs can help a firm achieve the desired business success. Recently, due to increasing importance of industry 4.0 and smart manufacturing topics, on top of rapid development of information technology and related opportunities for sensing operations on the manufacturing floor, lots of academic and industrial contributions are emerging focused on KPIs to improve manufacturing system performance.

Standard Development Organizations are playing their role too and several workgroups at worldwide level are involved in designing norms and standards on this topic. In this perspective, it is obviously desirable that all those groups guarantee the coherence and alignment of the defined concepts, from basic elements to complex models, since the standard editing phase. Therefore, any contribution that aims at identifying the relations between different existing standards is extremely useful to support industry in leveraging continuous process improvements across multiple similar operations.

In this paper two standards related to manufacturing industry are analysed and compared: the ISO18828 standard, related to production planning process, and the ISO22400 standard, related to manufacturing operations management, edited by two different workgroups in the International Organization for Standardization (ISO). These standards relate to consecutive phases in the product lifecycle: indeed, choices made during the production planning process influence and are influenced by production process parameters and this paper aims at highlighting the relations among the main concepts introduced in the two standards.

In the next paragraphs, the contributions related to standardisation of performance evaluation and indicators in manufacturing are recalled; then, ISO22400 and ISO18828 standards are first introduced and then analysed, putting in evidence connections and relations among some of the described concepts. Furthermore, interactions among the two standards are worked out to link them with the aim of allowing to optimise KPI throughout phases of the product lifecycle.

2. STANDARDISATION OF PERFORMANCE EVALUATION IN MANUFACTURING

Ever-growing customer demands result in product diversity, leading to increasing product and process complexity (Deuse et al., 2013), and cost pressures. Thus, manufacturers need to be able to manage complexity and improve transparency to establish target-oriented improvement processes to stay competitive. Performance management systems enable companies to determine aggregated quantitative depictions of the current situation

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(Preissler, 2008), thereby creating the basis for improvement and decision-making processes. Consequently, key performance indicators must be consistently used in analysing current processes and the way in which they are managed and controlled (Preissler, 2008). Even though KPI have a long tradition, there still is the need for effective tools and support in implementing management systems and tools (Krause & Arora, 2010).

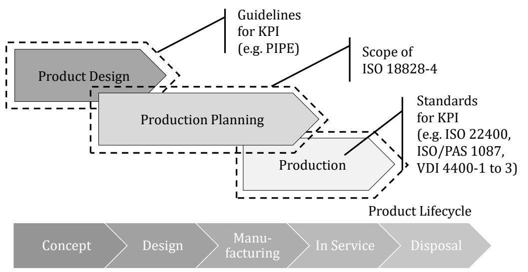

Fig. 1: different KPI domains among the standards

Current developments in digitalisation even increase the importance of KPI. First of all, implementation of sensors and embedded-systems as well as spreading connectivity of equipment and digitalized workflows enable companies to collect data with less effort and in real-time (Eickelmann et al., 2015). Second, further developments of data analytics allow to analyse and interpret data (ibid). This leads to a technology push of KPI in production and business processes. Besides availability of technologies to determine KPI cost-efficiently, the organisational framework has to be set to use KPI effectively and efficiently throughout the firm and the product lifecycle. Indeed, recently a great effort in standardization was put in order to favour the technology and the paradigm shift (Kupriyanovsky, 2017). Over time, different names and definitions for KPI have been defined (VDMA 66412-1, 2009), mostly based on company specific measures. Due to importance and increasing variety of KPI different norming activities took place to define and standardise KPI for different industries and departments (e.g. VDI2525; VDI4400-1 to -3; VDI4490; PAS1087) see Figure 1. Then, some authors focused on these standards proposing scientific contributions on the theme. Lindberg et al. (2015) based his research on the indicators introduced by the ISO22400 to propose a method to improve performance management. Hwang et al. (2016) introduced a framework that takes into account the hierarchical structure of a manufacturing system and its business activities in accordance with ISO22400 and IEC62264 (Hwang, Lee, Park, & Chang, 2017). Bauer et al. (2016) showed how the KPIs introduced by the ISO22400 standard can be used to reach high performance in a process production plant. Lastly, Brundage et al. (2017) built a graph-based visualization of ISO22400 KPIs relations. KPIs are mostly focused on production, but are not limited to this phase. So far, interdependencies between phases including their associated KPI have not been evaluated. Since the production is highly influenced by results of production planning, interdependencies of those two phases and the effects on production KPI have to be examined, leading to higher quality of planning results and improvement of KPI throughout phases of the product lifecycle. Thus, this new approach is a next step in standardisation of performance evaluation in manufacturing.

3. INDICATORS IN THE PRODUCT LIFECYCLE COMPARING ISO22400 AND ISO18828

Scope of work of ISO technical committee TC184 "Industrial automation system" is "standardisation in the field of automation systems and their integration for design, sourcing, manufacturing, production and delivery, support, maintenance and disposal of products and their associated services. Areas of standardisation include information systems, automation and control systems and integration technologies" (ISO, 2017). Inside this committee, two subcommittees have edited documents specifically related to key performance indicators: subcommittee SC4 "industrial data" (specifically, workgroup WG8 "Manufacturing process and management information", who edited ISO18828) and subcommittee SC5 "Interoperability, integration, and architectures for enterprise systems and automation applications" (specifically workgroup WG9 "metrics", who edited ISO22400). ISO18828 and ISO22400 have been both recently included as part of the current landscapes of standards in smart manufacturing system (Lu, 2016) More details on the scope of work of the selected standards are given in the next subsections.

3.1. *ISO22400*

ISO22400 "Key performance indicators for manufacturing operations management" specifies a framework for defining, composing, exchanging and using KPIs for manufacturing operations management (MOM). In its current state, it is divided in four parts: part 1 - *Overview, concepts and terminology* and part 2 - *Definitions and descriptions* have been published in 2014, while part 3 - *Exchange and use* and part 4 - *Relationships and dependencies* are in development. In part 2, KPIs for MOM are defined and described. Recently an amendment to part 2 containing energy KPIs was added.

ISO22400 is intended to be industry and process neutral. Indeed, it proposes a model to measure performance based on a general equipment structure hierarchy, and the execution of production orders. In this way, the KPIs may be applied by all manufacturing firms, regardless if their production is discrete, continuous or batch. MOM constitutes level 3 of the hierarchy introduced by the IEC62264 "Enterprise-control system integration" standard issued by the International Electrotechnical Commission. Thus, ISO22400 deals with KPI of functions within level 3 of a manufacturing facility, namely those functions that use raw materials, energy, equipment, personnel and information to produce products, with the required costs, qualities, quantities, safety and timeliness.

3.2. *ISO18828*

ISO18828 "Standardised procedures for production systems engineering" proposes the reference planning process between the product design process and the production process, hence, dealing with the production process design. In its current state, it is divided in 5 parts: part 2 - *Reference process for seamless production planning with a detailed description of the reference planning process* (see Figure 2) and part 3 - *Information flows in production planning processes* have been published in 2016 and 2017 while part 1 - *Overview*, part 4 - *Key performance indicators (KPIs) in production planning processes* and part 5 - *Manufacturing change management* are currently under development, despite some working drafts have been already reviewed and disclosed.

Part 4 is of specific interest for this analysis, elaborating the usage of key performance indicators in the production planning phase. The KPIs described in this part concern basically performance tracking of planning processes for engineering production systems and aim to improve the process of standardising the quality of production process monitoring. The structure for describing the KPIs in ISO18828-4 is inherited from ISO22400-2. Production planner can be a major beneficiary of a framework which approaches aspects such as production processes, information flows, key performance indicators and manufacturing changes. Indeed, production planning process information as well as statistical values from KPIs can influence manufacturing change processes and thus are input to Manufacturing Change. From there change process information are provided to the production system engineer in return.

Despite that ISO22400 and ISO18828 have been edited by different workgroups, the relationship between the production and production planning phases considered in these norms is quite strong. After the new product design, the end-to-end production process starts from the production process design, followed by production planning and manufacturing phases. Decisions taken during the production process design will influence manufacturing performance. In the first phase, indeed, several variables will be determined. Nevertheless, these variables will be influenced both by product characteristic and by manufacturing equipment characteristics, either new or already existing. For this reason, this paper investigates the connection points and the type of connections between the two standards.

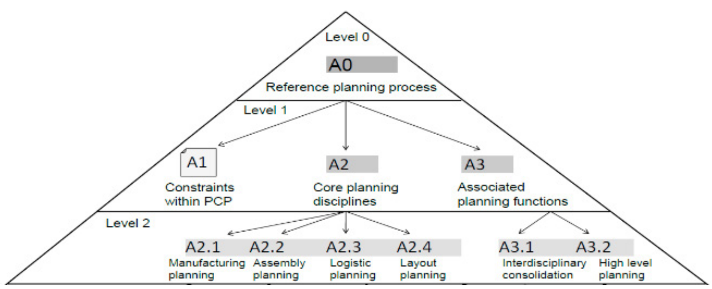

Fig. 2. ISO18828-2 reference planning process (level 0, 1, 2)

4. ANALYSING THE CONNECTIONS BETWEEN THE STANDARDS

This paper aims at highlighting the connections between ISO18828 and ISO22400, see Figure 3. With the aim of identifying possible connections between KPIs in both standards, at first the relationship among basic concepts introduced in ISO18828 and ISO22400-2 need to be analysed. At first, the reference production planning process for production preparation of ISO18828-2 will be introduced. This reference planning process model is based on a multi-level structure that progresses in steps in a top down approach where complexity of considered process chains increases. The production planning process is characterised by three main functions:

- constraints within the product creation process
- core planning disciplines, namely:
    - manufacturing planning (MAN)
    - assembly planning (ASS)
    - logistic planning (LOG)
    - layout planning (LAY)
- associated planning functions.

Focus of the proposed analysis is on information used and exchanged in the planning disciplines. Indeed, core planning disciplines are the main functions to be considered during production planning process. They derive information in input from the constraints. After that, the disciplines generate planning data output for the start of the production phase.

The production planning process encompasses several types of disciplines, and ISO18828 focuses on manufacturing, assembly, logistics and layout functions. The input and output of the core planning disciplines constitute the information flows that are received and sent. Therefore, the input represents data and constraints considered to plan the production process, while the outputs are related to the decisions taken to manage the production process.

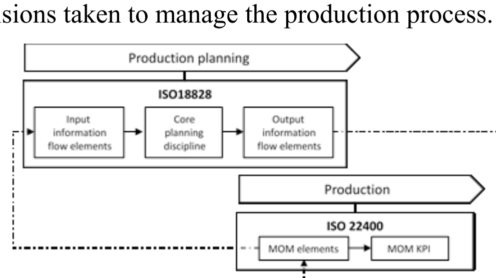

Fig. 3. ISO22400 and ISO18828

Differently, ISO22400 proposes a set of 38 KPIs to describe manufacturing performances. For each of them, the method and general concepts for computation are explained. The computation of KPIs is based on use of relevant measurements, called elements, clustered in logistical, quality and time elements. Clearly, the KPIs value depends on elements value. Therefore, elements were identified as the objects potentially influenced by the production design process and specifically by the core planning disciplines information flows.

4.1. *INFORMATION FLOWS AND KPI ELEMENTS*

In ISO18828-2, information flows can be divided into input and output flows. The input flows are the ones used by the core planning discipline to take decisions and to determine the output flows. Information flows exchanged between core planning disciplines are not analysed in this paper as they remain within the boundaries of the production planning process. Relationship between information flows in ISO18828 and KPI elements in ISO22400 can be intended in a twofold way: an output flow resulting from the completion of a core planning discipline may influence an ISO22400 KPI element, as well as an ISO22400 KPI element may influence a specific input flow used to perform the core planning discipline. Since the production planning phase – as it is intended in ISO18828 – may be an iterative process, the relationship has to be intended in both the ways, as shown in Fig 3.

In order to determine the possible influences or connections among the information flows in ISO18828-2 and the main basic elements in ISO22400-2, the information flows are classified in four classes:

- **Internal information flows**

The core planning disciplines exchange information using *internal* information flows. The precedence graph is an information identified by the assembly planning process and used by logistics and layout planning processes, while the detailed linking concept is sent by assembly and layout planning processes. The internal flows have not been analysed in relation with ISO22400 elements, as they are *consequent* to other flows.

- **Decision process information flows**

Other information flows are related to the decision process and build the class of *decision process* information flows, for example: adjusted planning scenario, change request, decision request, methodical support, modifications. They clearly all appear *indirectly* linked to manufacturing performance.

- **General information flows**

Combined concepts, costs, necessary resources, other requirements, resources, internal logistic concept, layout concept, logistic concept, manufacturing concepts, are *general* information flows, i.e. they are too generic to be punctually analysed in relation with performance elements. Indeed, they appear to be all somehow linked to the *overall* performances. Hence analysing the existing connection with the KPI elements and those kinds of flow wouldn't lead to any specific highlights, because they are too general. All the information flows influence somehow the KPI elements, and all the KPI elements value impact the information flows to be considered during the production planning.

- **Specific information flows**

The last class of information flows are *specific* information flows, for example: assembly times, cycle times, defined layout, ergonomics validation, bill-of-material inputs, manufacturing times, planned number of pieces, product structure (raw parts, shift models, time data per product, etc.). Indeed, these flows are those mostly related to MOM. In this paper, only the specific information flows are analysed. Indeed, in those cases only specific information flows will impact the KPI elements and vice versa. Therefore, it's useful to focus on those in order to highlight meaningful results

When the same flow is an input or an output of different core planning disciplines, different flows have been considered.

4.2. *CONNECTION TYPES*

Four alternatives of connection types between information flows and KPI elements have been determined (Battista & Schiraldi, 2013)

- High intensity connection (H) indicates a very strong relation between an information flow (ϕ) and an element (ε), e.g. are precisely related through a mathematical expression, such as $\phi = f(\varepsilon)$. Thus, changes in one concept directly influences the other.
- Medium intensity connection (M) indicates the existence of a relation despite a mathematical function binding both of them does not exist. The two concepts may be secondarily connected through a mathematical formula, e.g. $\phi = f(\mu)$ and $\varepsilon = g(\tau)$ and a variable Ω may exist so that $\Omega \in f(\mu)$ and $\Omega \in g(\tau)$. Changes in Ω influences both ϕ and ε.
- Low intensity connection (L) indicates a weak direct/inverse relation. A mathematical connection does not exist but there is a correlation that effect the information and the KPI element. The two concepts are independent, e.g. $\phi = f(\mu)$ and $\varepsilon = g(\tau)$, but a modification in ϕ may influence ε under specific conditions (known or unknown)
- No connection. The information flow ϕ does not influence the KPI element ε or vice versa. In Table 1, the cell is left blank when no connection is present.

5. DISCUSSION

Standards edited by International Organization are often criticized by two major points: first, they are universal, because they are conceived for the largest audience possible, which hampers immediate and direct applicability to real cases. Secondly, hundreds of standards are present, each one targeting a specific topic; despite the topic may refer to a narrow context, it may be treated in different documents and links and connections are not present or properly evidenced. As a result, the reader faces difficulties in finding information needed to address his specific problem. This paper offers a contribution on the latter point, aiming at facilitating the readers that search for support in production planning standardization. The classification of connection types between ISO18828-2 specific information flows and ISO22400-2 KPI main basic elements is not straightforward, due to the fact that relationships between concepts of different nature is to be found. Indeed, the two standards cover two consequential phases in the production lifecycle, the design and the execution, which should be tightly linked for continuous improvement. Information flows and KPI elements provide an instrument to abstract and model those phases and, thus, they allow to easily relate them. Indeed many ISO18828 information flows often implicitly refer to several different aspects that are specified in detail in ISO22400. For example, information related to “raw parts” in ISO18828 virtually encompass all the basic ISO22400 elements related with production quantities, e.g. scrap elements, rework elements, etc. In certain cases, the high intensity (H) connection is clearly visible: for example, the “assembly times” information flow – as an output of the assembly planning discipline – directly influence the actual personnel working time as well as the planned order execution time basic elements. A medium intensity (M) connection can be found, e.g., between the shift models used as in input to the manufacturing core planning disciplines and the planned scrap quantity basic element, because a high expected scrap rate would push the company to consider extra worktime for personnel, in order to meet the target good quantity volumes. Note that also the actual scrap quantity basic element would influence the shift models because the production planning disciplines are iterative processes, which take the production performance as input in order to refine the production system setting or design.

Table 1: Connections between ISO18828-2 information flows and ISO22400-2 elements

Core planning discipline	ASS	MAN	LOG	LAY	ASS	MAN	ASS	MAN	ASS	MAN	LOG	ASS	MAN	ASS	MAN	MAN	LOG	MAN	ASS	MAN	ASS
Flow Type	output	input	input	output	output	output	output	output	input	output	input	input	input	input	input	input	input	input	input	input	input
KPI elements / Information flows	Assy. Times	Assy. Times	Cycle times	Defined Layout	Ergonomics validation	Ergonomics validation	MBOM- input	MBOM- input	Mfg. Times	Mfg. Times	Planned No. of pieces	Planned No. of pieces	Planned No. of pieces	Product Structure	Product Structure	Raw parts	Shift models	Shift models	Shift models	Time data per product	Time data per product
consumables inventory				M			L	L													
consumed material				M			H	H	M		H	H	H								
equipment production capacity	H	H	H						H	H	H	H	H				H	H	H		
failure event		M	M						M	M	M	M	M				L	L	L		
finished goods inventory			L	M			L	L			H	H	H								
good part			L								H	H	H			H	M	M	M		
good quantity			L								H	H	H			H	M	M	M		
inspected part			M														L	L	L		
integrated good quantity			L								H	H	H			H	M	M	M		
order quantity (planned)			L								H	H	H			H	M	M	M		
other loss		H	H						H			H	H			H	M	M	M		
produced quantity			L								H	H	H			H	M	M	M		
production loss		H	H						H			H	H			H	M	M	M		
raw material inventory				M			L	L				L	L			H					
Raw materials				M			H	H	M			H	H			H					
rework quantity		H	H						H			H	H			H	M	M	M		
scrap quantity		H	H						H			H	H			H	M	M	M		
scrap quantity (planned)		H	H				H	H	H			H	H			H	M	M	M		
storage and transportation loss		L	L								H	H	H			H	M	M	M		
work in progress inventory			H	M								L	L								
busy time (planned)	H		H	M	H	H	M			H	H	H	H				H	H	H		
corrective maintenance time			H														H	H	H		
net operating time (actual)	H		H		H					H	H	H	H				H	H	H		
operating time (actual)	H		H		H					H	H	H	H				H	H	H		
operating time between failure			M																		
operation time (planned)	H		H		H	H				H	H	H	H				H	H	H		
order execution time (actual)	H		H	M	H	H				H											
order execution time (planned)	H		H	H	H	H	M			H											
personnel attendance time (actual)	H		H	M	H	H				H							H	H	H		
personnel work time (actual)	H		H	M	H	H				H							H	H	H		
preventive maintenance time																	H	H	H		
production time (actual)	H		H		H	H				H	H	H	H				H	H	H		
queuing time (actual)	H		H	H						H	L	L	L								
run time per item (planned)	H	H	H		H		M		H	H	H	H	H				H	H	H		
time to failure			M																		
time to repair			M																		
transport time (actual)			H	H																	
unit busy time (actual)	H		H		H	H				H	H	H	H				H	H	H		
unit delay time (actual)			H	M	H	H											H	H	H		
unit downtime (actual)			H														M	M	M		
unit processing time (actual)	H		H		H	H				H	H	H	H								
unit setup time (actual)	M		H		H	H				M	H	H	H				H	H	H		
unit setup time (planned)	M	M	H		H	H			M	M	H	H	H				H	H	H		

On the contrary, shift models may be loosely influenced by failure events, because unreliable technical resources would cause delays and increase of loading time, possibly resulting in the necessity of redesigning the personnel shift. This is an example of low intensity (L) connection between the two concepts. Finally, no connection is present, for example, between the information flow related to ergonomic validation and the raw material inventory element because the two concepts are completely unrelated.

Specifically, 28.27% of the total combinations between information flows and KPI elements resulted to have a high connection, 8.45% medium and 3.30% low. While the 59.98% of the combinations resulted not to have any connection. Specifically, 19% of the considered information flows resulted to be totally independent from the KPI elements proposed by the ISO22400.The total results of the connection analysis of the ISO18828 specific information flows of core planning disciplines and ISO22400 KPI main basic elements at MOM level are shown in Table 1.

6. CONCLUSIONS

This paper focused on the ISO22400 and ISO18828 standards integration, respectively addressing KPIs in manufacturing operations management and production planning process. As international standards are playing a key role in leading and shaping the smart manufacturing landscape, their coherence and their interoperability is of paramount importance.

The ISO18828 information flows have been classified and one class – the specific information flows class – has been taken into account and related to the main basic elements that in ISO22400 are used to define manufacturing operations management KPIs. Four alternatives of connection types have been defined (high, medium and low intensity connections on top of the no-connection alternative). The results aim at supporting standards' users, underlining the aspects that should be taken into account in order to consolidate and improve the considered lifecycle phases. In determining the connection types between the basic concepts in two standards, difficulties arose from the fact that the two standards frequently dealt with analogous concepts at different detail level. On top of this, ambiguity and vagueness in some definitions hampered the analysis. This leads to the conclusion that more effort as well as teamworking is needed from the ISO working groups editing the two standards in order to reach a higher level of precision, accuracy and coherence.

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