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Key performance indicators for manufacturing operations management – gap analysis between process industrial needs and ISO 22400 standard

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Abstract

ISO 22400 has defined a set of Key Performance Indicators (KPIs) to evaluate the performance of manufacturing operation. Despite it's conceived to be industry-neutral, the defined KPIs seem not to be perfectly suitable for process industry. Based on a survey performed in a process industrial company, this paper highlights the specific process industry's needs for evaluating the operational performance. Taking cue from this survey and by analyzing the characteristics and the needs of performance evaluation in process industry, the relevance of defined KPIs and comparison analysis between defined KPIs and needs-based KPIs are discussed, and some modifications are proposed.

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Keywords: ISO 22400; Key Performance Indicators (KPIs); process industry; comparison analysis.

1. Introduction

Key performance indicators (KPIs) are the quantifiable and strategic measurements that reflect enterprise's critical success factors[1], which is used to quantify the efficiency and effectiveness of manufacturing operations

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management[2]. Acknowledging the contributions and support of the KPIs, the operators and decision-makers can evidence the existing gap between the actual and desired performance and then take the corresponding actions for improvement. To facilitate and guide the specification and procurement of manufacturing operations management, the international standard ISO 22400 is drafted and established by the international organization for standardization.

The ISO 22400 standard "Automation systems and integration — Key Performance Indicators (KPIs) for manufacturing operations management"[1] provides an overview of the concepts, the terminology and the methods to describe and to exchange KPIs for the purpose of managing manufacturing operations. To evaluate the performance of manufacturing operations, a total of 34 KPIs are presented in its latest update – ISO 22400-2:2014. In the standards, the KPIs are described by means of their formula, corresponding elements, unit of measure, timing and other characteristics. The ISO 22400 aims at defining the most important and generally used measures for the manufacturing industry, and therefore it has been recognized for its potential contribution on manufacturing operations management[3]. Based on the ISO 22400, more and more further researches have been conducted both in theory and practice. Bauer et.al[4] applies the defined KPIs in the ISO 22400 to an amino acid production plant and demonstrate KPIs are the interface between scheduling and control, which can be used as a strategy for maximizing the plant performance. Vasilev[5] utilizes the ISO 22400 KPIs to calculate some important scheduling process parameters for scheduling in software industry. Zhu et.al[6] proposes an evaluation architecture of KPIs for manufacturing execution system and discussed the corresponding and normalized KPIs from the main operation aspects of production, quality, inventory, maintenance and energy in process industry. Johnsson[7] uses the ISO 22400 KPIs as the measurement parameter for designing the plant-wide feedback loops. Shen et.al[8] studies the benchmark for KPIs of manufacturing equipment by an approach of steady-state optimization. Zhu et.al[9] discusses the relationship of multi-KPIs when evaluating manufacturing equipment and proposes a multi-KPI coordination model to discern and balance the relationship among multi-KPIs.

Despite the efforts to make the standards generally applicable to all manufacturing industries, it seems to be primarily designed for evaluating performance of the discrete industry and hence only partly useful for the process industry[10]. Indeed, there exists a gap between the ISO 22400 research and industrial needs in process industry, and some defined KPIs cannot provide useful information or even cannot be computed for continuous processes. Taking the characteristics of the process industry into account, improvements and corrections of these 34 KPIs in the ISO 22400 should be made in order to evaluate the performance properly and accurately. Based on a survey conducted at a large process industry in Sweden, this paper evidences the difference between the process and discrete industry in relation to the standard and analyses the relevance of defined KPIs according to the industrial needs in the process industry. At the same time, the comparison analysis between defined KPIs and needs-based KPIs are discussed, and some modifications are proposed. Hence, the ISO 22400 standard becomes suitable for the process industry while keeping its generality.

The structure of this paper is organized as follows. The second section recalls the typical characteristics of the process industry and points out the difference between process and discrete industry. The gap between the defined KPIs in the ISO 22400 standard and process industrial requirements are discussed in sections 3. And comparison analysis between defined KPIs and needs-based KPIs and modifications are proposed in section 4. The section 5 discussed the contribution and the future research directions. Finally, the section 6 draws the conclusion.

2. Research gaps and process industrial needs

Two main types of manufacturing industry are generally identified by the way the products are realized, which are called process industry and discrete industry[11]. The process industry is defined as the industry in which the raw material undergoes conversion during a continuous process in order to become finished products[12]. While the discrete industry is related to the process where successive changes of discrete and analog states occur during the whole process, and the production is based on discrete time moments of instant and non-instant controls[13, 14]. The process and discrete industries have different characteristics, and hence can have different needs for performance measurements and, therefore, different needs for the KPIs. By investigating the differences between the typical process and discrete industries, some general conclusions can be drawn. To clarify what is meant by the respective terms in this paper, a summary of the difference is presented in Table 1.

Table 1. The difference characteristics of process and discrete industry.

Difference	Process industry	Discrete industry
Production modality	Continuous outflow	Discrete entity
Production orientation	Disassemble	assemble
Production process	Continuous	Discontinuous
Production form	Fluid-based	Pieces and parts
Work unit	Unit	Work cell
Production transparency	Invisible	Visible
Production runs	Open-ended	Well defined
Operation manner	Steady state	On-off

To further understand how the KPIs of the ISO 22400 standard relates to the process industry and their relevance, a survey[15] has been conducted in a large chemical process industry company in Sweden. The survey is based on a course project about the application of KPIs defined in ISO 22400. According to the survey, there are ten KPIs defined in ISO 22400 with high relevance（allocation ratio, throughput rate, utilization efficiency, quality ratio, setup rate, scrap ratio, fall off ratio, machine capability index, finished goods ratio and equipment load ratio） and all of them are related to the perspectives of production, quality and energy. Furthermore, the survey confirmed the general assumption that, in process industry, the production process is designed in a straightforward manner, which indicates the units only work at one process at a time. At the same time, several or all units tend to be active at all time during a production cycle, which makes it hard to analyze the process and determine how much raw material was used to produce a specified quantity of the product. Although this might be true for some cases in the discrete industry as well, it is a more common occurrence in the process industry. In addition, the definition and measure of quality in process industry can be typically different from those in discrete industry. The gaps between ISO 22400 standard and process industrial needs are presented in Fig 1.

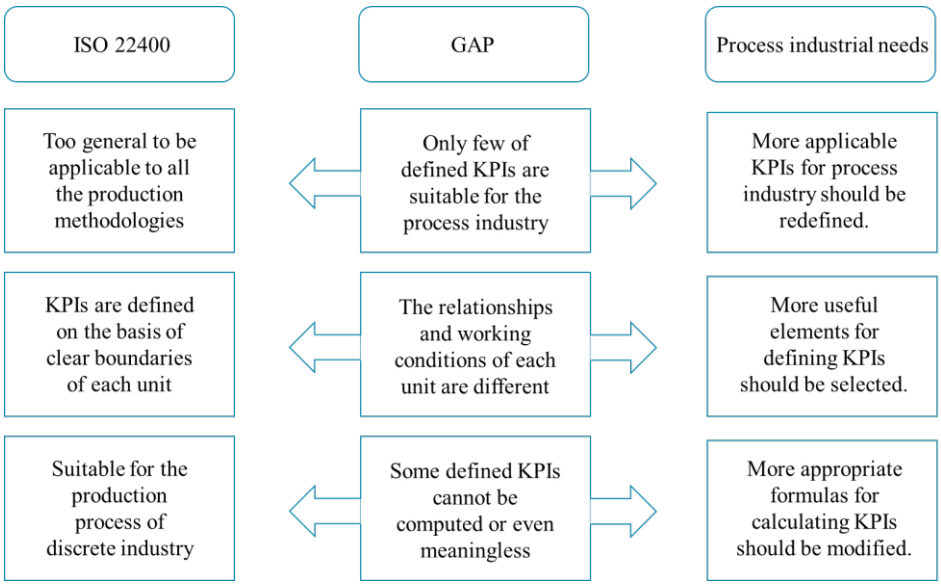

Fig. 1. Gaps between ISO 22400 and process industrial needs.

Therefore, some of the KPIs defined in ISO 22400 should be redefined in order to be applicable in process industry, and additional KPIs should be included.

3. Comparison analysis and improvement

The characteristics of the process industry should be taken into account when designing, selecting and using KPIs. Hence, according to the characteristics and gaps analysis in section 2, the 34 KPIs defined in the ISO 22400 standard are discussed one by one from their usability and measurement elements. For the usability, we divide these KPIs into three categories, including NU set, UU set and UC set. NU set includes the KPIs which cannot provide useful evaluating information or make no sense in the process industry. UU set contains the KPIs which are still useful and no need to be changed when applying in the process industry. While UC set consists of the KPIs should be redefined or modified with some specifications in the process industry. Similarly, the measurement elements are also discussed by the same division. The applicability of the defined KPIs in the process industry is presented in Fig 2.

	KPI	action \ element	ADET	AOET	APAT	APT	APWT	AUBT	AUPT	AUST	PBT	EPC	PRI	E	GP	GQ	PQ	PSQ	RQ	SQ	IGQ	IP average inventor	Cm	OL	PL	STL	PMT	FE	TBF	TTF	TTR	CMT	LSL	USL	x/	x//	σ
			UU	UC	NU	UC	NU	UU	NU	UC	UC	NU	UU	UU	UU	NU	UC	UU	UC	UU	UU	UU	NU	UU	UU	UU	UU	UU	UU	UU	UU	UU	UU	UU	UU	UU	UU	UU
not useful (NU)	Availability						x					x											x															
	First pass yield														x																							
	Production process ratio			x			x																														
	Worker efficiency				x			x																													
useful and no changed (UU)	Actual to planned scrap ratio																	x		x																	
	Comprehensive energy consumption													x			x																				
	Corrective maintenance ratio																										x				x					
	Critical machine capability index																																x	x	x		x
	Critical process capability index																																x	x		x	
	Effectiveness					x							x				x																				
	Equipment load ratio											x					x																				
	Finished goods ratio															x							x														
	Integrated goods ratio																				x		x														
	Machine capability index																																x	x			x
	Mean operating time between failures																											x	x								
	Mean time to failure																											x		x							
	Mean time to repair																											x			x						
	Net equipment effectiveness index					x			x			x				x																					
	Other loss ratio																						x	x													
	Overall equipment effectiveness index											x				x																					
	Process capability index																																	x	x		
	Production loss ratio																						x		x												
	Quality ratio															x	x																				
	Rework ratio																x		x																		
	Scrap ratio																x			x																	
	Storage and transportation loss ratio																						x			x										
	Technical efficiency	x				x																															
Useful but changed (UC)	Allocation efficiency						x				x																										
	Allocation ratio			x			x																														
	Fall off ratio															x	x																				
	Inventory turns			x													x																				
	Setup ratio							x		x																											
	Throughput rate			x													x																				
	Utilization efficiency					x		x																													

*ADET: actual unit delay time, AOET: actual order execution time, APAT: actual personnel attendance time, APT: actual production time, APWT: actual personal work time, AUBT: actual unit busy time, AUPT: actual unit processing time, AUST: actual unit setup time, PBT: planned busy time, EPC: equipment production capacity, PRI: planned run time per item, E: comprehensive energy consumption, GP: good part, GQ: good quantity, PQ: produced quantity, PSQ: planned scrap quantity, RQ: rework quantity, SQ: scrap quantity, IGQ: integrated good quantity, IP: inspected part, Cm: machine capability index , OL: other loss, PL: production loss, STL: storage and transportation loss, PMT: preventive maintenance time, FE: failure event, TBF: operating time between failure, TTF: time to failure, TTR: time to repair, CMT: corrective maintenance time, LSL: lower specification limit, USL: upper specification limit, x/: arithmetic average, x//: average of average values, σ : standard deviation.

Fig 2. The applicability of the defined KPIs in the process industry.

It should be noticed that, in the ISO standard, 4 KPIs are in NU set, including worker efficiency, availability, production process ratio and first pass yield. 30 KPIs are useful, including 7 KPIs in UC set, such as allocation ratio, throughput rate, allocation efficiency, utilization efficiency, setup rate, fall off ratio and inventory turns, and 23 KPIs remain unchanged in UU set.

There are two cases for the KPIs need to be changed in the UC set. One is the KPIs need to be modified with some specifications in order to be applicable in the process industry. Production rate indicator is usually applied to evaluate the process performance instead of throughput rate defined in the ISO 22400, which focuses on the produced volume

over a period of production time in the process industry. As a result, the modified production rate is applied when calculating the inventory turns indicator in process industry. Because the process production cannot be divided into discrete steps as needed, the fall off ratio is modified to measure how efficient the input material is used in the process and related with finished goods ratio defined in the ISO 22400. Another case is the KPIs cannot be computed due to the modelling issues and should be redefined. Considering the concerned measurement elements of these KPIs are changed in process industry, new KPIs are proposed to substitute these kinds of KPIs according to the specific characteristic in process industry. The proposed KPIs are therefore able to better describe the process industry characteristics and measuring the relevant performances. Due to the similarity of allocation efficiency and utilization efficiency in the process industry, we proposed 3 KPIs to substitute the original allocation ratio, utilization efficiency and setup rate separately in detailed based on the KPIs description method in the ISO 22400, as shown in Table 2, Table 3 and Table 4.

Table 2. Proposal of a new KPI for the allocation ratio in the process industry

Alternative Allocation Ratio for Process Industry (AR-PI)	
Content	
Name	Alternative Allocation Ratio for Process Industry (AR-PI)
Description	AR-PI is the relationship of actual production rate (APR) divided by maximum production rate (MPR).
Scope	Units and process-unit
Formula	AR-PI = APR / MPR
Unit of measure	%
Range	Min:0 Max:100
Trend	The high the better
Context	
Timing	On demand, periodically
Audience	Supervisor, management
Production methodology	Continuous

Table 3. Proposal of a new KPI for the utilization efficiency in the process industry

Alternative Utilization Efficiency for Process Industry (UE-PI)	
Content	
Name	Alternative Utilization Efficiency for Process Industry (UE-PI)
Description	UE-PI is the relationship of the actual production rate (APR) and the planned production rate (PPR).
Scope	Units and process-units
Formula	UE-PI = APR / PPR
Unit of measure	%
Range	Min: 0 Max: 100
Trend	The high the better
Context	
Timing	Periodically
Audience	Supervisor, management
Production methodology	Continuous

Table 4. Proposal of a new KPI for the setup rate in the process industry

Alternative Setup Rate for Process Industry (SR-PI)	
Content	
Name	Alternative Setup Rate for Process Industry (SR-PI)
Description	SR-PI is the relationship between the setup costs and the total unit contribution margin of produced quantity.
Scope	Work unit, product
Formula	SR-PI = setup costs / total unit contribution margin of produced quantity
Unit of measure	%
Range	Min: 0 Max: 100
Trend	The lower the better
Context	
Timing	On demand, periodically
Audience	Supervisor, management
Production methodology	Continuous

4. Discussion

The ISO 22400 standard defines and describes 34 KPIs for manufacturing operation management. The aim of the standards is to be general enough to guarantee the KPIs' applicability. In fact, by the analysis, even if the standard indicates differently, the indicators appear be primarily designed for discrete industry. Due to the vast difference between process industry and discrete industry, the defined KPIs in the ISO 22400 cannot meet the requirements of the practical process production. In order to improve the KPIs in the ISO 22400 to properly evaluate performance in a process industry setting, the different characteristics of process and discrete industry are analyzed. At the same time, the practical requirements in the process industry are acquired and the gaps between the KPIs defined ISO 22400 and process industrial needs are discussed based on the survey of the process industry company in Sweden. Through the comparison analysis between defined KPIs and needs-based KPIs, some modifications are proposed to make the ISO 22400 more applicable in the process industry. In order to verify and validate the usability of the originally defined KPIs and improved KPIs, more case studies should be carried on and the actual industrial data should be used to demonstrate their effectiveness in the further study. In addition, according to the specific requirements in process industry, some related and important KPIs should be added and in-depth analyzed.

5. Conclusion

This paper considers the ISO 22400 Automation systems and integration — Key Performance Indicators (KPIs) for manufacturing operations to address the performance management in the process industry. Based on the characteristics analysis and conducted survey in a process industry, the gaps between the process industrial needs and ISO 22400 standard are discussed. By the comparison analysis between defined KPIs and needs-based KPIs, the corresponding adjustments and modifications are made for the KPIs in the process industry. This research makes the ISO 22400 KPIs more applicable and suitable for evaluating performance in the process industry.

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