Determination of ISO 22400 Key Performance Indicators using Simulation Models: The Concept and Methodology

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Abstract: The study focuses on developing an approach to determining production key performance indicators (KPIs). Different types of KPIs have been defined and their distribution has been determined. The article deals with the problem of how to determine indicators. A review of KPIs and ISO 22400 was carried out. The author's own methodology for simulation determination of indicators was proposed. The conducted case studies were prepared on the basis of sample processes in order to indicate the mechanism of proceeding in the author's methodology. The research used one of the available systems for designing and optimizing virtual models of production processes and showed the possibilities of its use in the analysis of production processes.

1 INTRODUCTION

In today's highly competitive and dynamic business environment, manufacturing industry faces new challenges that require a broader view of the four main classes of production attributes, i.e. cost, time, quality and flexibility, as well as the need to increase productivity.

The problem with a reliable and unambiguous assessment of production efficiency is the lack of ability to use comprehensive indicators to determine it. Productivity is analyzed at the level of workstation, individual operation, as well as the entire production process and production lines. There are difficulties in understanding and selecting specific indicators for research, and there is a growing need for quick and clear key performance indicators for sustainable production (Kibira, Brundage, Feng, Morris, 2018).

Depending on the specifications of the production process and the industry in which the company operates, production lines can vary considerably in design and configuration (Zwierzyński, 2018), which can also affect how these processes are measured.

The performance indicators are a reference point for employees, reflect current process characteristics, facilitate collaboration rules that are defined, clear and acceptable to all parties. At the operational level, the indicators are used to solve current problems in a dynamic way, while when planning and setting strategies, they are used to analyze and build objectives based on results. KPIs include a set of individually selected indicators, which can be either financial or non-financial (Rydzewska-Włodarczyk, Sobieraj, 2015).

The aim of introducing KPIs into the production process is to provide support to managers and to enable them to quickly, easily and transparently review the overall state of production processes in all segments in a sustainable way. When a section fails to meet predefined requirements, the manager is quickly informed to find the cause and take further action. In this way, potential damage can be avoided or minimized (Rakar, Zorzut, Jovan, 2004).

2 ISO 22400 KEY PERFORMANCE INDICATORS

According to ISO 22400, KPIs are defined as quantifiable and strategic measurements that reflect the critical success factors of an organization. Key performance indicators are very important for understanding and improving production efficiency. ISO 22400 is a standard defined by the International Organization for Standardization that defines how to define, compose, exchange and use Key Performance Indicators (KPIs) to support the management of

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production operations. ISO 22400 defines these principles in a way that is as independent as possible of the industry in which the manufacturing company operates. It is defined by two catalogues: ISO 22400-1:2014 (ISO 22400-1:2014) and ISO 22400-2:2014 (ISO 22400-2:2014).

ISO 22400 specifies an industry-neutral framework for defining, composing, exchanging, and using key performance indicators (KPIs) for manufacturing operations management (MOM), as defined in IEC 62264-1 for batch, continuous and discrete industries. ISO 22400-1:2014 provides an overview of what a KPI is, presents concepts of relevance for working with KPIs including criteria for constructing KPIs, specifies terminology related to KPIs, and describes how a KPI can be used (ISO 22400-1:2014).

ISO 22400-2:2014 specifies a selected number of KPIs in current practice. The KPIs are presented by means of their formula and corresponding elements, their time behaviour, their unit/dimension and other characteristics. ISO 22400-2:2014 also indicates the user group where the KPIs are used, and the production methodology to which they correspond (ISO 22400-2:2014). With reference to equipment, the KPIs in ISO 22400-2:2014 relate to work units, as specified in IEC 62264 (IEC 62264).

In the literature, a constant upward trend can be observed in the context of the number of studies related to KPIs, and a steady increase in the number of studies on this problem can be observed (Kikolski, 2019).

The indicators describing the operation of the production system and being an object of the ISO 22400 standard, are characterized by a structured structure and interrelationships. In ISO-22400-2 all of the 34 KPIs are divided into four groups in production systems. These four types are production, maintenance, quality and inventory operations management.

The production operations management KPIs deal with production line activities. These KPIs are mostly related to product managers and workers that work close to the production lines.

The maintenance operations management KPIs are regarding the maintenance of all the manufacturing resources.

The quality operations management KPIs are of importance in any manufacturing system, they ensure that all products produced are of best quality. These KPIs indicate the performance of whole production line in terms of quality perspective.

Inventory operations KPIs deal with activities such as transportation of raw material from warehouse to production lines and picking up finished products for storage.

Table 1 presents a set of KPIs of the ISO 22400 standard (P – production, M – maintenance, I – inventory, Q – quality).

Table 1: ISO 22400 key performance indicators.

KPIs	P	M	I	Q
Worker efficiency	X			
Allocation ratio	X			
Throughput rate	X			
Allocation efficiency	X			
Utilization efficiency	X			
Overall equipment effectiveness index	X			
Net equipment effectiveness index	X			
Availability	X			
Effectiveness	X			
Quality ratio				X
Setup ratio	X			
Technical efficiency	X			
Production process ratio	X			
Actual to planned scrap ratio				X
First pass yield				X
Scrap ratio				X
Rework ratio				X
Fall off ratio				X
Machine capability index	X			
Critical machine capability index	X			
Process capability index	X			
Critical process capability index	X			
Comprehensive energy consumption	X			
Inventory turns			X	
Finished goods ratio	X			
Integrated goods ratio	X			
Production loss ratio	X			
Storage and transportation loss ratio			X	
Other loss ratio			X	
Equipment load ratio	X			
Mean operating time between failures		X		
Mean time to failure		X		
Mean time to repair		X		
Corrective maintenance ratio		X		

Source: Usman, 2018.

The values achieved by the KPIs are very helpful in the decision-making process, enabling the identification of problems and the undertaking of corrective or improvement actions. Proper use of information from the KPI measurement should contribute to more effective management of the organisation's resources (Antczak, Gębczyńska, 2016).

3 RESEARCH METHODOLOGY

KPIs are used to focus on the expectations and needs of users including the results of production operations. The purpose of the ISO standards is to enable the highest possible use of the KPI definition in a wide variety of industrial sectors and regional markets. According to ISO 22400, the following steps are used to select and use KPIs in manufacturing companies (ISO 22400-1:2014):

- identification of operations and elements of operations assessed,
- setting targets to be achieved using performance indicators,
- description of operational activities when performance indicators are used to meet expectations,
- definition of criteria for evaluation and measurement of performance indicators,
- choice of performance indicators,
- evaluation of the results in relation to the objectives of the performance indicators,
- execution of actions in order to achieve the objectives set.

A similar approach (Figure 1) was presented by Rakar, Zorzut and Jovan. They proposed an 8-step model of KPI introduction in the form of a loop.

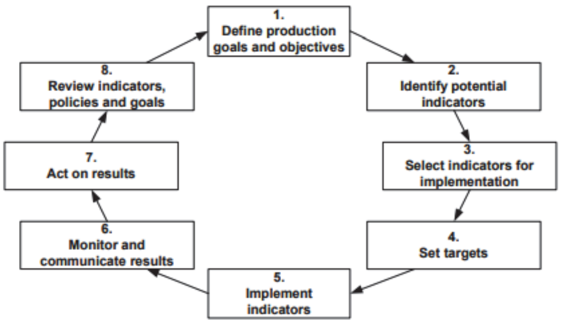

Figure 1: Closed-loop model for defining and measuring production key performance indicators (Rakar, Zorzut, Jovan, 2004).

The first step in identifying KPIs is to define production targets that reflect the organisation's mission. The next step is to identify potential indicators showing performance and production targets. The third step is to select the indicator to be implemented, the next step is to select the objectives. The fifth stage involves the implementation of indicators, contains a set of data, their calculation, evaluation and interpretation of results. This step is the most labour-intensive and therefore requires the participation of staff, especially middle management of the company. The next step is related to monitoring the results. In order to continuously improve the processes, the results of the use of indicators should be periodically evaluated. The seventh step consists of actions based on results, which are considered a critical step in the application of the indicator. The last step is the review of indicators, principles and objectives. This is an important step as it is assumed to be the basis for setting new targets and indicators. In this step, a possible elimination and selection of new indicators is carried out.

Approach consists of using simulation models to research. The creation of a simulation model of a process is a multi-stage task (Law, 2008). Figure 2 presents the seven-step approach to conducting a successful simulation study.

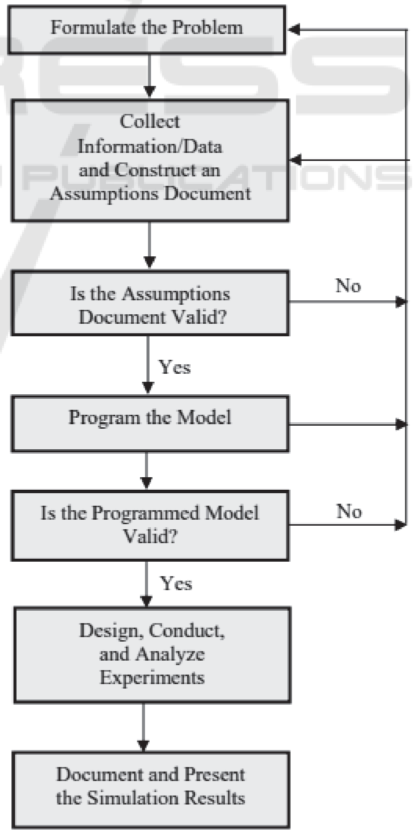

Figure 2: A seven-step approach for conducting a successful simulation study (Law, 2008).

The simulation of production processes is a technique used for solving problems occurring during the manufacturing process. As a method, a computer simulation is a system of research activities, i.e. a structure of stage activities aimed at achieving a research objective.

Modelling the production process involves the creation of a virtual manufacturing process that allows conducting a simulation and collecting statistics. Statistics facilitate conducting reports and comparing selected settings of the parameters that characterise workstations. Computer models can be freely improved, and further simulations can be applied to various variants and settings anticipated by the user (Kikolski, 2016).

Simulation studies are applied to and are used in many scientific fields (Halicka, 2016). The application of a simulation in production processes constitutes a form of experimenting with a computer model. Its objective is to provide an answer to the question on how the production system will react to various situations, according to arranged scenarios. The application of simulation models allows for a more effective selection of manufacturing strategies by enterprises.

On the basis of studies on the creation of simulation models and the determination of key performance indicators, the author's own methodology for the determination of KPIs with using simulation models has been developed (Figure 3).

The proposed methodology consists of nine steps.

The first stage is to collect information about the process that is needed to create a simulation model - its course, number of workstations, connections between them and machine parameters.

The second stage is to create a virtual model of the production process. This is one of the most important stages, because errors in the project implementation will cause incorrect results in the KPIs determination. It is very important to develop a model at the appropriate level of detail of the simulated model. Many model designers, supported by powerful simulation tools, tend to model everything regardless of the project goals.

In the third stage, production targets are formulated, to which the results of simulation variants will refer.

The fourth step is to select a key performance indicator that will be analysed. It should be noted that it is possible to determine the selected indicator in a created virtual production environment. If some parameters are missing in the model, it becomes impossible to determine which indicators use the selected data (e.g. cost or energy consumption).

In the fifth stage, the results are collected and analysed, which leads to the sixth stage - determining whether the level of the chosen indicator is satisfactory. If so, we move on to stage seven. If the measurement of the indicator in the planned production plan is too low, you should go back to stage five and correct the production assumptions.

Stages seven and eight are the implementation of the selected production plan and continuous monitoring of performance, which may lead to further production targets.

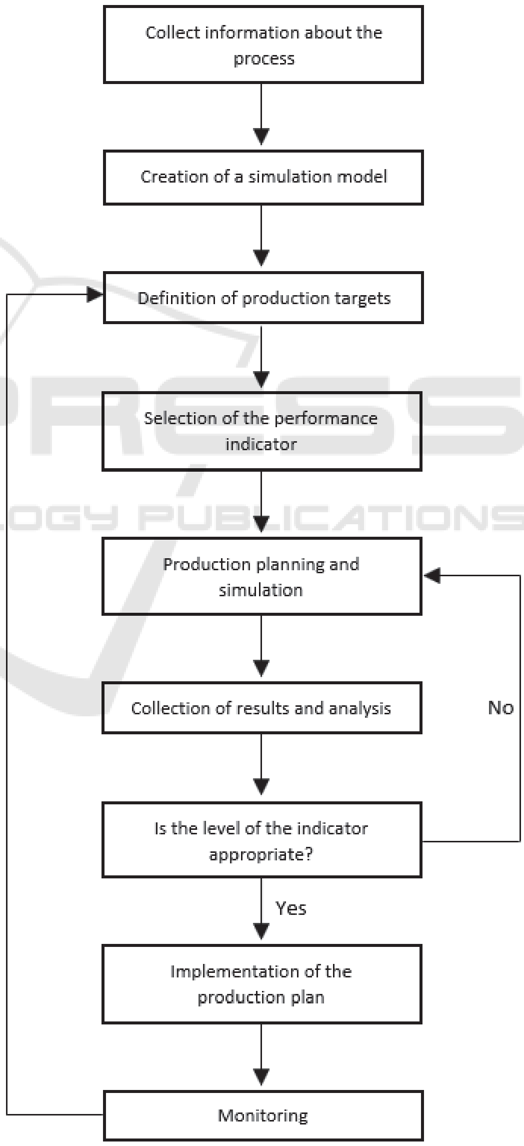

Figure 3: Proposal of methodology for the determination of KPIs with using simulation models.

Simulation of performance indicators is part of the original methodology for the facility layout design methodology, which will consist of two sections: a part supporting the design of a new layout of workstations and a part focused on the reconstruction of the existing layout of workstations. Regardless of the approach to the problem with the production systems, the measurement of production efficiency is a key element of the manufacturing systems (Kikolski, Ko, 2018).

4 CASE STUDY

Knowledge of phenomena and processes is the goal of many research programmes. Different methods are used for this purpose, ranging from practical actions involving observation to theoretical analyses, often with the use of a mathematical apparatus. Nowadays, computer simulation is a very important and effective research method. Computer simulations are also indicated as the most frequently chosen tools for analysing the possibilities of process optimization in production engineering (Kikolski, 2017). Building a simulation model of a production process is a multi-stage task. Modeling consists of creating a virtual production process, which enables simulation and collecting statistics. Statistics make it possible to prepare reports and compare selected settings of workstation parameters. Computer models can be freely improved and subsequent simulations can be performed for various variants and settings provided by the user (Kikolski, 2016).

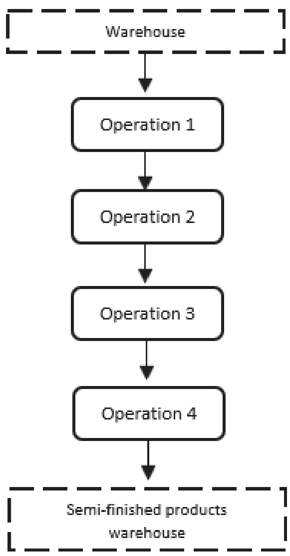

Figure 4: Schematic diagram of a analysed production process.

The analysis of indicators refers to the production of one of the components of the electrical installation box. The production of a component consists of four activities, after which it is transferred to the semi-finished products warehouse. The diagram of the process is shown in Figure 4.

The study was conducted on three different product variants (A, B and C) in a specific number of orders (11 pieces A, 4 pieces B and 7 pieces C), and the analysis covered part of one shift - 3 hours and 15 minutes. Table 2 presents unit processing times of elements at all workstations and the set-up times between orders. The process is handled by two workers.

Table 2: Times of material processing.

	A	B	C	Set-up
Operation 1	0:04	0:06	0:07	0:00
Operation 2	0:20	0:24	0:20	6:00
Operation 3	0:49	0:52	0:45	2:50
Operation 4	0:45	0:45	0:55	9:48

Source: own study.

The research was carried out using the Siemens product - Tecnomatix Plant Simulation, which is one of the tools available on the market for creating simulation models. It combines technological fields, production engineering and logistics. A simulation model is shown in Figure 5.

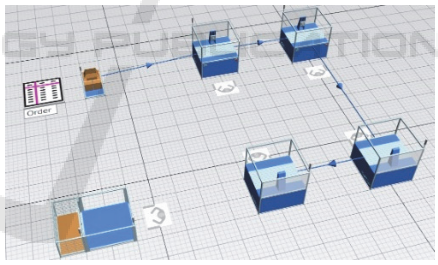

Figure 5: Simulation model of the analysed process.

The simulation resulted in six different variants of the production plan. The number of semi-finished products produced in individual experiments is presented in Table 3. The results of detailed indicators are presented in subsequent points of the study.

Table 3: Times of material processing.

	Sequence	Semi-finished products
Simulation 1	ABC	34
Simulation 2	ACB	35
Simulation 3	BAC	37
Simulation 4	BCA	33
Simulation 5	CAB	40
Simulation 6	CBA	33

Source: own study.

The highest production efficiency (40 units) was achieved in the fifth production plan (CAB sequence), while the lowest production value (33 units) was achieved in scenarios 4 and 6 (BCA and CBA).

Simulation studies were conducted for selected indicators in each of the four groups: production, maintenance, inventory and quality. The choice of indicators consisted in identifying one indicator from each group and testing it.

4.1 Production KPI - Worker Efficiency

The analysed process is handled by two employees - one responsible for material processing (operations 1-3) and one responsible for the finishing of semi-finished products (operation 4) and their transport to the warehouse. The results of their performance are presented in Table 4 and Table 5.

Table 4: Statistics on the workload of worker 1.

	Sim 1	**Sim 2**	**Sim 3**
Working	25,20%	31,41%	29,06%
Setting-up	31,03%	25,34%	30,61%
Transporting	0%	0%	0%
En-route to job	3,72%	3,76%	3,89%
Waiting	40,06%	39,49%	36,44%
	Sim 4	**Sim 5**	**Sim 6**
Working	33,42%	29,96%	26,26%
Setting-up	29%	30,90%	30,82%
Transporting	0%	0%	0%
En-route to job	3,72%	4,19%	3,72%
Waiting	33,86%	34,95%	39,21%

Source: own study.

Table 5: Statistics on the workload of worker 2.

	Sim 1	**Sim 2**	**Sim 3**
Working	14,46%	15,02%	14,83%
Setting-up	28,92%	28,92%	28,92%
Transporting	1,16%	1,20%	1,26%
En-route to job	1,21%	1,24%	1,31%
Waiting	54,25%	53,63%	53,68%
	Sim 4	**Sim 5**	**Sim 6**
Working	17,68	17,37%	13,89%
Setting-up	27,46	28,92%	30,92%
Transporting	1,13	1,37%	1,13%
En-route to job	1,21	1,41%	1,21%
Waiting	52,53%	50,94%	52,86%

Source: own study.

The simulation shows that worker 1 achieves the best work performance in the simulation scenarios 4 and 5. Worker 2 achieves the best percentage of work in the fifth scenario.

4.2 Maintenance KPI - Mean Time to Repair

Parameters of the tested model concerning Maintenance indicators do not allow for their random generation - they were defined in the project assumptions and are generated in a fixed form during the simulation. The MTTR indicators are shown in Table 6.

Table 6: Mean time to repair times in simulated model.

	MTTR (in minutes)
Operation 1	0:30
Operation 2	6:10
Operation 3	1:10
Operation 4	12:00

Source: own study.

Simulation software allows to determine the constants or resulting from selected distributions (e.g. Gamma) mean times to repair.

4.3 Inventory KPI - Inventory Turns

Inventory turns is specified as the ratio of the throughput (TH) to average inventory. It is commonly used to measure the efficiency of inventory, and represents the average number of times the inventory stock is replenished or turned over (ISO 22400-2:2014). Inventory turns results are presented in Table 7. Average inventory in this study is 39,3.

Table 7: First pass yield ratio.

	Inventory turns
Simulation 1	0,865
Simulation 2	0,891
Simulation 3	0,941
Simulation 4	0,839
Simulation 5	1,018
Simulation 6	0,839

Source: own study.

The highest inventory turns indicator has been achieved in Scenarios 3 and 5.

4.4 Quality KPI - First Pass Yield

First pass yield is a mathematical formula used to measure quality and efficiency in production. It shows in particular how many elements go through the production process without any problems. The indicator is presented in Table 8.

Table 8: First pass yield indicator ratio.

	First pass yield
Simulation 1	89,5%
Simulation 2	89,7%
Simulation 3	92,5%
Simulation 4	86,8%
Simulation 5	93%
Simulation 6	89,2%

Source: own study.

In simulation 1 an FPY of 89,5%, for example, tells that 89,5% of items are moving through the system without any issues. 10,5% percent of items are scraps or reworks, which can be a time and cost burden on final production. The higher the FPY, the more efficient your production processes. In this study, the highest percentage of FPY can be observed in the simulation 5 (CAB sequence) – 93%.

5 CONCLUSIONS

The article presents a proprietary methodology for determining the level of key performance indicators using simulation models.

The wide availability of simulation tools and powerful computers creates appropriate conditions for the extensive use of simulation methods in industry. Simulation models are used to reduce the risk of failure when introducing significant changes to the existing generation systems. After the model is generated, a simulation analysis is carried out to determine the individual components of the process. Siemens Plant Simulation software was used to develop the models.

In order to obtain correct analysis results, it is necessary to define the basic properties of the system correctly. The collected information was used to build virtual manufacturing processes and determine their basic tasks. Simulation models were developed in accordance with the adopted assumptions concerning, among others, the size of production batches, simulation times and performance of individual operations, as well as the availability of workstations. Out of several production scenarios, the highest efficiency in all measurements was shown by the fifth scenario with the CAB sequence.

The methodology will be still tested and possibly extended in the course of further research. The next field of research will be testing methodology in pull production systems (Pull System).

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