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Analysis of the maturity of process monitoring in manufacturing companies

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Abstract
The economic progress of recent years has contributed to the fact that both the quality of products and services offered and ISO standardization have become priority criterion that determines the success of manufacturing enterprises. Therefore, the monitoring and supervision of processes carried out in manufacturing companies is a key issue. These aspects support the achievement of key economic and quality objectives. The paper presents the results of a study on manufacturing enterprises in the context of process monitoring maturity. The research objective of the study was to determine the level of maturity in the use of process monitoring techniques and methods in manufacturing enterprises. The subject of the research were the techniques and methods used by the surveyed enterprises in such areas as: production management, machinery park management, warehouse management, transport management, inventory and supply management and IT tools. In order to determine the level of maturity, the author's model was used, according to which the level of maturity of a manufacturing enterprise in the area of process monitoring depends on the instrumentation that is used in it.

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1. Introduction

Current and possible future trends in the global economy (including globalization, rising unemployment and recession) force companies to critically self-assess their own process monitoring systems. The dynamically progressing automation and robotization of many sectors of modern economies clearly shows that in the cost structure of an enterprise, the implementation of instruments and tools to improve key processes for manufacturing companies, including the cost of maintenance of systems, is an increasing share of the total cost of the company (Jalali and Johannesson, 2013; Tan et al., 2019; Di Franvescomarino et al. 2018; Pacana et al., 2016; Ostasz et al., 2020; Krynke, 2021). Experts on the quality of process implementation (e.g. W.E. Deming, J. Juran, Ph.B. Crosby, G. Taguchi, K. Isikawa, M. Imai, A. Feigenbaum) even indicate that the costs of the applied instruments in process improvement will be a cost area that will have a significant impact on the competitiveness of enterprises in the global market (Frąś et. al. 2016; Pacana et al., 2014; Knuplesch et al., 2015; Teinemaa et al. 2016; Meyer, 2021).

In order to strengthen their position in the market through improvement, manufacturing companies should establish the methods and criteria necessary to assess their course (Wolniak, 2011; Pacana et al., 2019). Moreover, to be able to talk about the correct management companies should monitor, measure and analyze individual processes in order to implement possible improvements. The correct improvements can be identified through the use of various types of quality management instruments (Siwek et. al. 2006). In a significant number of articles and book publications related to quality management issues, one can see an approach indicating that the methods and tools used within quality management are extremely important in the context of supporting the development and improving the quality of final products that reach buyers (Borkowski et al. 2014; Pacana et al., 2020; Kowalczyk and Maleszka, 2010; Łuczak and Maćkiewicz, 2006; Sage and Rouse, 2009; Żuchowski and Łagowski, 2004). This view is related to the fact that quality management instruments are characterized by universality in terms of application - they can be used to monitor the entire production cycle already from the design stage, through manufacturing to the control of the finished product and to control the product at each stage of production (Wadsworth et al., 2002).

The purpose of the study is to identify the implementation of methods or monitoring activities related to process management along with the diagnosis of the growth phases of the studied organization and process maturity assessment using the presented diagnostic model. An element of novelty in the study was the attempt to determine the maturity level and to characterize the approach to process monitoring in the context of enterprise size.

2. Maturity model of process monitoring in manufacturing companies - research framework

In order to determine the maturity level of process monitoring in manufacturing companies, a literature review was conducted. The subject of the research was a collection of scientific studies on the issues of process monitoring and supervision. The research was performed in the fourth quarter of 2021. Scientific databases such as Web of Science and SCOPUS were used. The result of the performed literature research was the following conclusions:

- despite the growing interest in the issue of process monitoring in manufacturing companies and the increasing number of scientific studies, there is a research gap regarding the assessment of maturity level.
- there are systems for monitoring processes identified in manufacturing companies in organizations - they account for 37.4% of the analyzed papers, while the rest concern all or selected main processes.
- the most common models are those consisting of 2-4 maturity levels. The reason for a relatively small number of implied levels in companies is that each of them requires distinguishing factors specific for a given level. As a result, there is a correlation between the increase in the number of maturity levels and the degree of difficulty of model presentation.
- the assessment against a specific level should be strictly carried out. Only when all the requirements specified for a particular level have been fully achieved is that level achieved.

The list of prerequisites emerged from the literature was included in the model of process monitoring maturity study in manufacturing enterprises.

In the developed model, six areas of manufacturing enterprises were evaluated, including: production management, machinery park management, warehouse management, transport management, inventory and supply management, IT tools. It should be noted that in each manufacturing company the areas of production management, machinery park management, IT tools may be identified, while the other specified areas may not exist. Each of the areas is subject to a separate assessment of five levels (P0-P5). In the model, level P0 indicates the lack of maturity of the analyzed area, while P5 indicates full maturity in terms of process monitoring. The diagram of the model is shown in Figure 1.

	P1	P2	P3	P4	P5
PM01	0.30	0.25	0.25	0.15	0.10
PM02	0.20	0.20	0.20	0.10	0.10
PM03	0.10	0.10	0.10	0.05	0.05
PM04	0.10	0.10	0.10	0.10	0.50
PM05	0.05	0.05	0.05	0.00	0.00
PM06	0.15	0.15	0.10	0.10	0.10
PM07	0.10	0.01	0.10	0.00	0.00
PM08	0.00	0.00	0.10	0.15	0.15
PM09	0.00	0.00	0.10	0.10	0.10
∑	1.00	0.86	1.10	0.75	1.10
MMP01	0.10	0.10	0.05	0.05	0.05
MMP02	0.20	0.20	0.10	0.10	0.10
MMP03	0.00	0.00	0.05	0.05	0.10
MMP04	0.00	0.05	0.05	0.03	0.03
MMP05	0.00	0.10	0.30	0.30	0.30
MMP06	0.30	0.30	0.30	0.30	0.35
MMP07	0.10	0.10	0.20	0.20	0.20
∑	0.70	0.85	1.05	1.03	1.13
ITT01	0.20	0.20	0.20	0.30	0.30
ITT02	0.15	0.15	0.10	0.05	0.05
ITT03	0.10	0.10	0.10	0.15	0.15
∑	0.45	0.45	0.40	0.50	0.50

	P1	P2	P3	P4	P5
TM01	0.05	0.05	0.10	0.10	0.10
TM02	0.00	0.00	0.00	0.05	0.05
TM03	0.05	0.05	0.10	0.15	0.15
TM04	0.20	0.02	0.02	0.05	0.05
∑	0.30	0.12	0.22	0.35	0.35
SPM01	0.20	0.20	0.25	0.25	0.30
SPM02	0.15	0.15	0.20	0.20	0.22
SPM03	0.30	0.30	0.25	0.20	0.20
SPM04	0.10	0.10	0.10	0.00	0.00
SPM05	0.00	0.00	0.00	0.05	0.05
SPM06	0.05	0.05	0.05	0.00	0.00
SPM07	0.20	0.20	0.25	0.25	0.25
∑	1.00	1.00	1.10	0.95	1.02
WM01	0.30	0.30	0.25	0.25	0.20
WM02	0.20	0.20	0.25	0.30	0.30
WM03	0.10	0.10	0.10	0.15	0.20
WM04	0.30	0.30	0.30	0.10	0.05
WM05	0.10	0.15	0.20	0.25	0.30
WM06	0.05	0.05	0.00	0.00	0.00
WM07	0.00	0.00	0.50	0.50	0.10
WM08	0.00	0.00	0.10	0.10	0.15
WM09	0.10	0.10	0.10	0.15	0.15
∑	1.15	1.20	1.80	1.80	1.45

Fig. 2. Concept of process monitoring maturity model - maturity levels. Source: own study

The research assumes that the level of maturity of a given enterprise depends on the stage of evolution in supervision and monitoring of processes. In order to determine the stage of maturity it is necessary to measure it. The model includes process monitoring tools (39 tools), which were assigned to specific areas. The tools used were commonly known and used in organizations to monitor processes. A list of 100 most commonly used tools identified in a study (Richard and Grinsted, 2016) was used, which the authors supplemented with tools used within production management. Table 1 shows the tools included in the study.

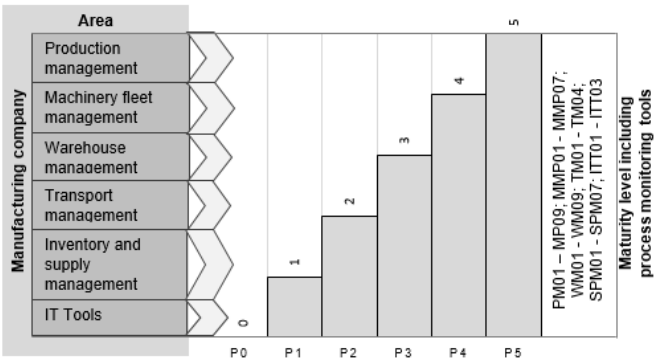

Fig. 1. The concept of process monitoring maturity model. Source: own study

The presented concept of measuring the maturity level of process monitoring taking into account the implemented tools is derived from the work performed by M. Fertscha (Fertscha,

2016) and Werner-Lewandowska, K., and Kosacka-Olejnik, M. (Werner-Lewandowska and Kosacka-Olejnik, 2019).

The specific maturity level is determined by the tools used in the area. With the fact that in a given area there is a diverse number of them and each tool shows a different impact on the achieved maturity level. The results of the expert research made it possible to determine the degree of influence of a given tool on the maturity level, as shown in Figure 2.

Referring to Table 1 and Figure 2, among others, 9 tools are listed in the PM (production management) area. The maturity level P6 is not affected by PM05 and PM07. Among the tools listed in this area, the impact of each tool is differentiated. The weights of the tools were determined by the experts.

The model assumes that for each process monitoring maturity level, there is a specific reference value, which is the sum of all tool values within the level. In the study, this value will be needed to define the actual level of the company in a particular area. The model assumes that a higher level of logistics maturity is associated with a higher level in the excellence of tool implication and application.

Table 1. Process monitoring tools included in the model

No.	Process monitoring tools
	production management
1.	Production Planning (MPRII) (PM01); Production Audit (PM02); Flow Chart (PM03); Gantt Chart (PM04); Mind Map (PM05); DMAIC Process Improvement (PM06); Balanced Scorecard (PM07); KPIs (PM08); PDCA (PM09)
	management of the machine park
2.	OEE Index (MMO01); FMEA (MMP02); Pareto-Lorenz Analysis/ABC Analysis (MMP03); Ishikawa Diagram (MMP04); MES (MMP05); TPM (MMP06); SMED/OTED (MMP07)
	warehouse management
3.	Pareto-Lorenz/ABC analysis (WM01); Warehouse equipment selection (WM02); 5S/6S (WM03); Using a warehouse management system (WM04); Inventory planning (MPRII system) (WM05); Warehouse location (WM06); Warehouse space (WM07); Material handling equipment (MHE) selection (WM08); Warehouse audit (WM09)
	transport management
4.	Matching customer demand with supplier capabilities (TM01); Transportation audit checklists (TM02); Transportation management system (TM03); Transportation emissions calculations (TM04)
	stock and procurement management
5.	Inventory and supply management system overview (SPM01); Inventory management audit (SPM02); Material requirements planning (SPM03); Machine parts inventory management (SPM04); Inventories (SPM05); Economics of order quantity (EOQ) (SPM06); Maintaining safety stock (SPM07)
	IT tools
6.	RFID (ITT01); Web-based purchasing/procurement (ITT02); IT cloud, IT applications (ITT03)

The research was carried out in 80 Polish manufacturing enterprises of various sizes depending on the level of employment. The survey covered companies in the automotive, aerospace, and foundry industries. The survey was conducted in the third and fourth quarters of 2021. The structure of the surveyed enterprises depending on the employment parameter is presented in Table 2.

Table 2. Structure of the surveyed enterprises according to the employment parameter

Employment size ranges	E=1	E<10	11<E<50	E>250
Number of enterprises in a given employment group	5.3%	7.9%	52.6%	34.2%

The study specified 4 ranges of business size: microenterprises (sole proprietorships), small enterprises (with up to 10 employees), medium enterprises (with 11 to 50 employees), and large enterprises (with more than 250 employees). Micro manufacturing companies, which employ less than 10 people, are a minority among the studied group, but the study excluded one-man enterprises, treating them as a separate category.

The maturity assessment is implemented in three stages. The first stage consists in conducting a survey. This makes it possible to identify the tools that are used or known in the surveyed manufacturing companies. The survey questionnaire consisted of a metric and a core part including 45 questions. The questions focused on familiarity with and use of process monitoring tools. Among them were questions such as: "Is Pareto - Lorenz analysis/ ABC analysis in your enterprise: not known, known and not applied, used". A survey test was performed on 10 companies and then a representative group of companies was selected. The representative group in the study was selected in a non-returnable way, that is, each unit could participate in the study only once.

The second stage of the process monitoring maturity assessment consisted of processing the data obtained at the first stage - parameterizing the influence of individual identified tools on the maturity level. This was done according to the principle:

- the tool is not known in the production enterprise - value "-1",
- the tool is known but not used in a manufacturing enterprise - value is "0"
- the tool is used in a manufacturing company - value is "1".

The third stage of the research evaluated the maturity level of process monitoring within the specified areas of the manufacturing enterprise.

Stage three was based on two assumptions:

- due to the fact that such areas as warehouse management and external transport may not have occurred in manufacturing enterprises, the presence of these areas is identified using survey questions.
- each analyzed area was tested in the aspect of immaturity. It was concluded that the lack of knowledge of half of the listed tools assigned to a specific area indicates an immature level (level P0). In this situation further steps of analysis are not performed.

In order to determine the maturity level of the selected areas, the reference values of the impact of particular tools (data in Figure 2) and responses obtained from the survey are used. The value assigned to each answer concerning knowledge/use of the tools (value: -1, 0, 1) is multiplied by the reference value (impact strength), and then the total impact of the tools on a given maturity level is calculated.

As a result, the resulting numerical value (0-100%) indicates the degree to which a particular area is mature in terms of logistics process monitoring - the maturity parameter. The highest value of the parameter indicates the achieved maturity level. Table 3 shows an example of the maturity parameter calculation for the production management area.

The result from the survey shown in Table 3 indicates that production management maturity has been achieved at the P5 level.

Table 3. Assessment of process monitoring maturity level - production management area

ID number	Received answer	Numerical value	Effects of a particular tool on the degree of maturity				
			P1	P2	P3	P4	P5
PM01	YES	1	0.30	0.25	0.25	0.15	0.10
PM02	NO	0	0.00	0.00	0.00	0.00	0.00
PM03	Don’t know	-1	0.00	0.00	0.00	0.00	0.00
PM04	YES	1	0.10	0.10	0.10	0.10	0.50
PM05	YES	1	0.05	0.05	0.05	0.00	0.00
PM06	No	0	0.00	0.00	0.00	0.00	0.00
PM07	YES	1	0.10	0.01	0.10	0.00	0.00
PM08	NO	0	0.00	0.00	0.00	0.00	0.00
PM09	YES	1	0.00	0.00	0.10	0.10	0.10
The total value of tool impact at a given maturity level			0.55	0.41	0.60	0.35	0.70
Reference value for the maturity level in the area			55.00%	47.67%	54.55%	46.67%	63.64%

3. Results

Many process maturity diagnosis models are presented in the literature. These models can be divided into those concerning the state of identified processes in the organization and such models that capture the process maturity of the enterprise as a whole (Röglinger et al., 2012). The model, aa on which a significant number of process maturity models were developed was the Capability Maturity Model (CMM). Due to its effectiveness, it was adapted to other industries which influenced the creation of subsequent versions of the model As a result of the evolution of the CMM model, the concept of CMM Integration (CMMI) was created indicating five levels of process maturity (Bartkowiak et al., 2019, p. 24). And in the Business Process Maturity Model (BPMM), the levels of the model capture not only the process aspect, but also the management and the goal set (Krukowski, 2016, p. 158). One can also distinguish models that refer to a more holistic approach to process maturity of an organization, i.e. those that do not focus only on processes, but also on key areas in achieving particular levels of process maturity (Raczyńska, 2017, pp. 61-73). Such models include, for example, D.M. Fisher's model, which examines five areas (strategy, control, process orientation, employees, and technology) that influence an organization's process development (Fisher, 2004, pp. 1-7). However, among the considerable number of models, there is a model missing that refers not so much to process maturity but to process monitoring maturity, which was proposed in the study.

The result of the performed research on the level of maturity of process monitoring in manufacturing enterprises in relation to the analyzed areas is presented in Figure 3.

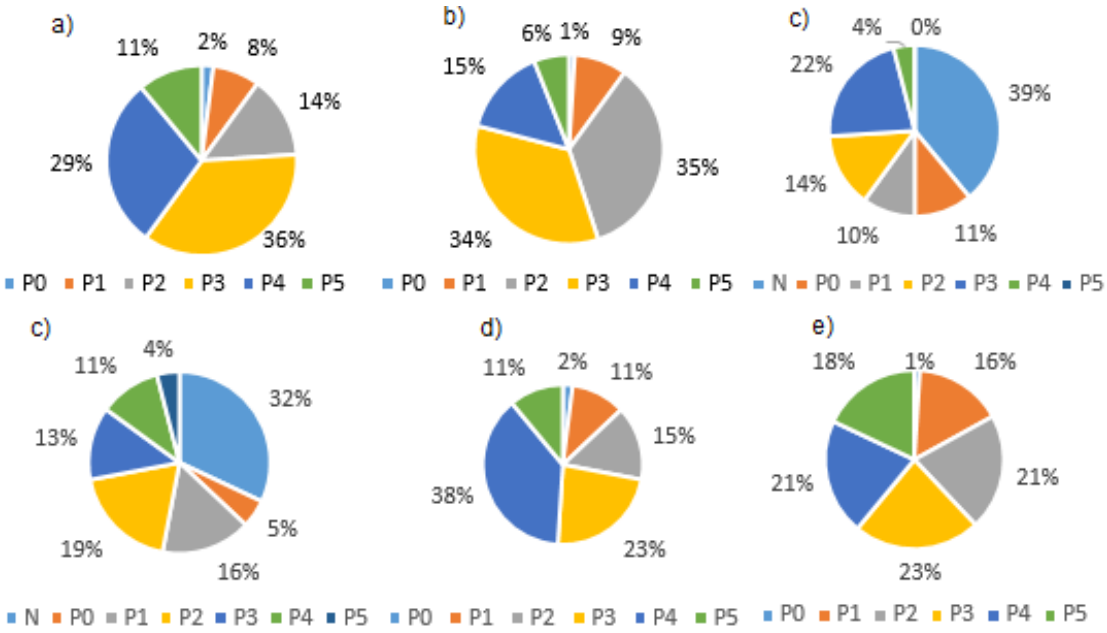

Fig. 3. Maturity level of process monitoring in manufacturing companies a) production management; b) management of the machine park; c) warehouse management; d) transport management; e) stock and procurement management; f) IT tools. Source: own study

Based on the respondents' answers in relation to each of the analyzed areas, the following conclusions can be drawn:

- production management - 1) only 2% of the surveyed companies were excluded from the assessment of the production area, because they do not use more than half of the production management tools assigned to this area. This fact applies to micro and small companies. 2) Regardless of the size of employment, the largest number of companies in the survey reaches P3.
- Management of the machine park - 1) the maximum level of maturity in the analyzed area achieved by large companies is P4, whereas for micro and small companies it is P2. 2) Companies know and use the tools listed in the survey that are related to machine park management, regardless of the size of the company.
- warehouse management - 1) 39% of the surveyed companies have not been assessed in this area, as they do not have a warehouse (mainly micro companies). 11% of the companies were not assessed in terms of maturity, as they demonstrated knowledge of the indicated tools at a level of less than 50%. 2) Medium and large enterprises reach maturity level from P2 to P3 in the analyzed area.
- transport management - 1) large companies mainly reach level P1 (75%) and do not reach level higher than P2; 2) the highest levels of maturity (P4, P5) in the area of transport management are achieved by micro and SME.
- stock and procurement management - 1) 2% of the surveyed companies were excluded from the assessment in this area, mainly micro and small companies. 2) the highest percentage of responses indicated the P4 maturity level (these were mainly medium and large enterprises).
- IT tools - 1) 1% of the surveyed companies represent the lowest level of logistics maturity - P0 in the area of IT solutions (this indication referred to micro enterprises); 2) large enterprises with more than 251 employees reach maturity levels P2 and P4 in terms of IT solutions applied.

The results obtained indicate the usefulness of the developed model for studying the maturity of process monitoring in manufacturing companies.

4. Summary and conclusion

The study shows that, regardless of the size of the manufacturing enterprise, they use process monitoring tools in the following areas: production management, fleet management, warehouse management, transport management, inventory and supply management and IT tools to support process management. It was found that the process monitoring maturity level analysis model presented in the study is an effective methodology.

In the study of warehouse and transport management, the largest number of companies, respectively 39% and 32%, were excluded from the analysis due to the indicated areas. Which may cause a disturbingly low level of familiarity with the listed tools in these areas.

The study shows that the number of companies that achieve the highest level of maturity of process monitoring is very small. The P4 and P5 level is reached by the majority of small and medium enterprises.

Further research will be done to expand the model to include more tools for both monitoring and improvement of manufacturing enterprises. Another direction of research will be the diagnosis of the level of maturity of enterprises in industries such as: automotive, aviation, and foundry. The limitation of the diagnostic model is the need for tools in the analyzed enterprises and the willingness of enterprises to participate in the study.

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制造企业过程监控成熟度分析

關鍵詞

管理与质量
过程
过程监控
改进

摘要

近年来的经济进步促成了这样一个事实，即所提供的产品和服务的质量以及 ISO 标准化已成为决定制造企业成功与否的优先标准。因此，对制造公司进行的过程的监控和监督是一个关键问题。这些方面支持实现关键的经济和质量目标。本文介绍了在过程监控成熟度背景下对制造企业的研究结果。本研究的研究目的是确定制造企业使用过程监控技术和方法的成熟度。研究的主题是被调查企业在生产管理、机械园区管理、仓库管理、运输管理、库存和供应管理以及 IT 工具等领域使用的技术和方法。为了确定成熟度水平，使用了作者的模型，根据该模型，制造企业在过程监控领域的成熟度水平取决于其中使用的仪器。