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Proposal for Evaluating the Efficiency of Production Processes Using External and Internal Key Performance Indicators

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The paper focuses on proposing a method for implementing key performance indicators (KPIs) to assess the effectiveness of manufacturing processes. For the evaluated processes of precision parts machining, the share of non-conforming products was proposed as a KPI, evaluated as both an external and an internal indicator. The external indicator EXTppm expressed the quantity of faulty products to the volume of production. Its monthly development during 2022 was evaluated. The internal KPI represented the internal share of non-conforming products INTppm during 2022 which was related to the order of part A. Towards the conclusion causes for not attaining the targeted KPI values are pinpointed, and recommendations are put forth to enhance the productivity of manufacturing processes.

Keywords: Key Performance Indicator (KPI), Process Performance, Faulty Product, Non-conforming Product, Maintenance

1 Introduction

To assess process efficiency and uphold competitiveness, it is crucial to oversee individual activities within the enterprise. To achieve this, the introduction of key process performance indicators is deemed suitable. These indicators are designed to monitor specific activities within the enterprise, fostering effective and competitive operations in the market. While various key performance indicators exist for both manufacturing and non-manufacturing sectors, determining the most relevant ones remains a challenge, as each enterprise must prioritize and establish its own set of key performance indicators [1].

Key performance indicators (KPI) can be precisely defined as factors within the organization's management that are of critical importance, as stated in the STN EN ISO 9004:2010 standard in chapter 8.3.2 [2]. For lasting success, companies must undergo performance measurement and define their key performance indicators (STN EN ISO 9004:2010). KPIs are beyound a doubt necessary tools for measurement and control in all organizational processes. These indicators enable the assessment of the effectiveness of activities and aid in optimizing all the utilized resources. They specifically target aspects of the organization's performance crucial to both current and future success. KPIs serve as essential navigational tools for managers, providing insights into whether the business is on a successful trajectory or deviating from a prosperous path.

KPIs should align with the corporate strategy and competitive factors of the organization, emphasizing a results-oriented approach [3, 4]. They need to be meaningful, coherent, cross-purpose driven, and standardized for objective comparisons across different organizations [5]. Numerous research studies have explored the definition and identification of benefits linked to the implementation of KPIs in enterprise operations [6, 7]. We can state that all authors agree that the most important contribution of KPI is based in increasing the productivity of business processes and increasing product quality due to the introduction of measurable manufacturing indicators [8, 9].

After reviewing many literature sources, it is clear that the introduction of key performance indicators brings many benefits to companies that decide to implement them. The following benefits in particular are:

- They provide transparent goals for employees;
- They improve productivity;
- They improve the quality of managers' decision-making processes,
- They make evaluations of work results more objective and purposeful,
- They strengthen organizational efficiency,
- They increase the quality of the services provided
- They establish clear security metrics [10, 11, 12, 13].

Nowadays, it is also possible to use a methodology that includes the phases of process analysis, design, implementation and verification in order to obtain an interface that displays the key indicators of production within Industry 4.0 [14]. Different models such as EAM (the Enterprise Analysis Model) or Quality Matrix can be used to select KPI [15, 16]. KPIs are selected from different areas of the enterprise, such as maintenance, they can also have an impact on sustainability and thus on the future competitiveness of the enterprise [17, 18].

2 Material and methods

The study was conducted in an engineering enterprise specializing in machining both metallic and non-metallic parts through chip removal processes [19]. The ware of the analyzed enterprise (see Fig. 1) find applications in window system mechanisms, the furniture industry, hydraulic assemblies, but primarily in the production of renowned automobile manufacturers and manufacturers of heavy trucks.

Fig. 1 *Example of produced pieces* [12]

The manufacturing process encompasses a diverse array of components primarily produced through chip machining technologies, ranging from straightforward turned parts to intricate machined pieces completed via grinding, rolling, or milling. The primary emphasis is on CNC machining for both metallic and non-metallic parts. The core of the manufacturing technology involves machining centers, CNC lathes primarily handling bar materials, and compact horizontal centers.

The enterprise primarily tracks financial order indicators but recognizes the importance of extending monitoring to indicators that encapsulate the overall process performance. The introduction of Key Performance Indicators (KPIs) within the examined enterprise follows a step-wise approach, where the successful fulfillment of each step is crucial for the effectiveness of the overall KPI implementation. The sequential order of these steps is pivotal, influencing both the scheduling and integration itself of KPIs into firm processes.

An algorithm has been developed to systematically plan the various stages of introduction in manufacturing processes. This algorithm outlines the individual steps of the KPI implementation procedure, including the evaluation of process productivity and possible follow-up response to react to the failure to meet the goal:

- Creating a Process Map: Develop a comprehensive map outlining the production processes.
- Determination and Specification of Measured Processes and Process Owners: Identify the specific processes and their respective owners that will be subject to measurement.
- Defining Key Process Performance Indicators (KPIs): Clearly define the KPIs that will be used to gauge process performance.
- Data Sources and Input Measurement: Identify relevant data sources and establish a method for measuring values associated with selected KPIs.
- Analyzing and Reporting Current Process Performance: Conduct an analysis of the current performance of the processes and generate comprehensive reports.
- Evaluation of Process Performance: Assess the extent to which process performance goals have been achieved.
- Proposal for process improvement measures: Identify and establish measures aimed at enhancing process performance.
- Control measures and data collection and analysis: Verify the implementation of measures, and repeatedly collect and analyze data to ensure ongoing compliance and improvement.

Based on step „Defining Key Process Performance Indicators“, Key Performance Indicators (KPIs) were subsequently proposed for the evaluated production. The identified indicators characterizing product quality include: the count of complaints, plan fulfillment, the count of non-conformities, total productivity, and production time per unit of production. From the KPI proposals, the following were used for our analysis:

- Number of complaints (non-conforming products identified by the customer);
- Number of non-conforming products (non-conformities detected during control processes in production).

For the exact expression of the KPI, ratio indicators EXTppm and INTppm were created, see Tab. 1. The following text contains a mathematical expression of the indicated indicators.

***Tab. 1** Designed and evaluated KPIs*

EXTppm	the cumulative number of non-conformities per month in proportion to the cumulative volume of products delivered in a period per month
INTppm	the cumulative number of non-conformities per month in proportion to the cumulative volume of products produced in a period per month

To assess and report the current performance of processes concerning customers, the monthly Key Performance Indicator (KPI) for evaluating the count of claimed products was employed. The outcome is represented as a value expressed in parts per million (ppm) as external ppm for a one-month duration. The inputs for this calculation include the count of delivered parts within the one-month period and the count of defective parts during the same timeframe. The formula for calculating the external ppm for a one-month period is expressed as follows. This formula provides a quantitative measure of the count of defective parts per million delivered, offering insights into the external quality of process productivity with respect to customer satisfaction (1):

$$EXTppm_{montly} = \frac{On}{Oc} * 1000000\ [-], \quad (1)$$

Where:

O_n …The volume of reported non-conformities for a period per month [pcs],

O_c …Cumulative volume of products delivered over a period per month [pcs].

From the point of view of the quality of internal processes, the performance of orders of part A was evaluated according to the count of non-conforming units identified in production during 2022. The result is the expression of the internal ppm for the given part A for individual orders. It is always evaluated the production period of a specific order after its completion. The inputs are the count of manufactured products per order and the count of non-conforming products created during a specific order. The INTppm indicator (2) is an expression of the overall stability for the production period of a specific order:

$$INTppm = \frac{Vn}{Vc} * 1000000\ [-], \quad (2)$$

Where:

V_n …Volume of non-conforming products in the order [pcs],

V_c …Total volume of products produced in the stated order [pcs].

3 Results and discussion

The calculation procedure outlined in the text above was applied in identifying and designing the Key Performance Indicator (KPI) implementation procedure within the analyzed enterprise. Following the implementation of the procedure, individual KPIs were assessed based on the collected data. It is essential that the data processing be presented in a suitable format for clear comprehension of process performance assessment. Moreover, the data should be purposefully organized in a time-ordered manner to facilitate the compilation of future development trends from the collected information.

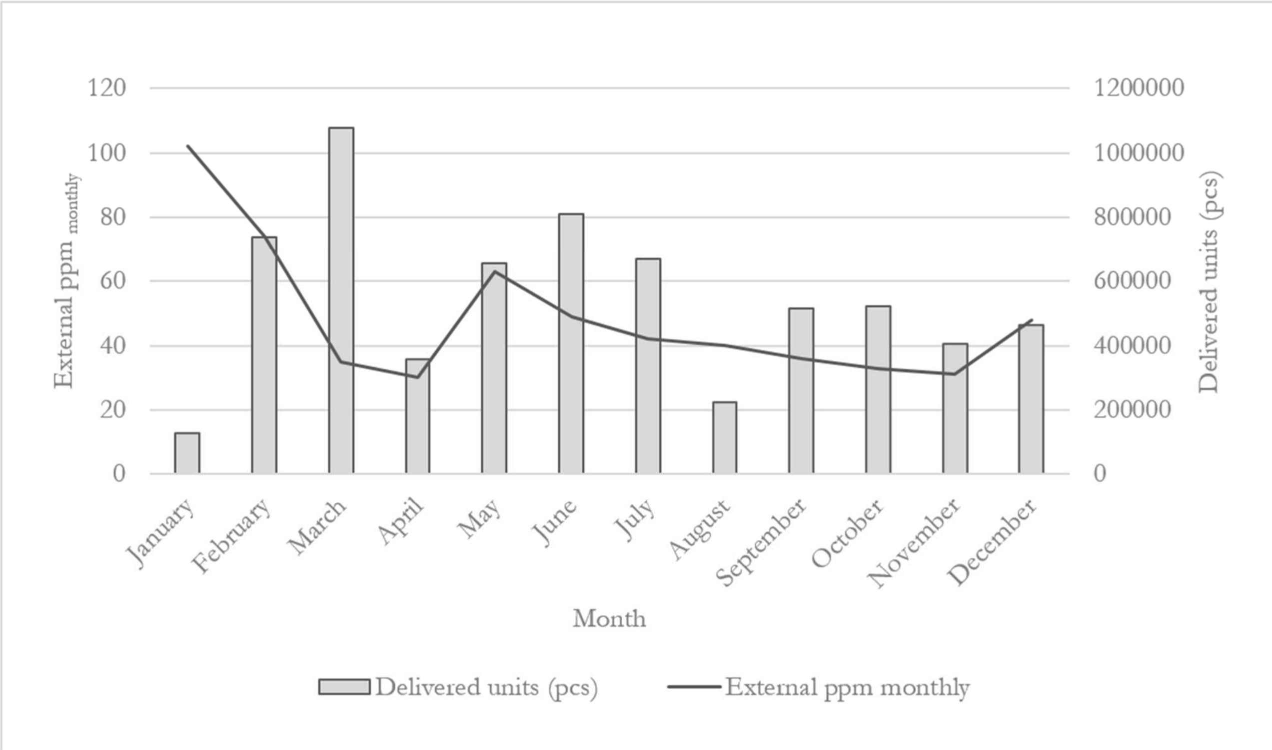
To evaluate the long-term productivity of manufacturing processes concerning the count of non-conforming products, the relevant data spanned from January 1, 2012, to December 31, 2022. Data collection on non-conforming products within the production was conducted through the corporate information program Dialog. Information on non-conforming products was collected periodically within each shift throughout the product's production period.

3.1 KPI evaluation - the count of faulty products via EXTppm per month

In the initial phase, the research focused on assessing the productivity of production processes, specifically pertaining to product quality. This involved a monthly assessment of the count of products with defects, expressed as EXT-ppm (external parts per million) per month. The results of monitoring this Key Performance Indicator (KPI) were retrospectively rated for the preceding year, serving as an illustrative demonstration of the development direction over the course of the year.

The outcomes of data collection for the analyzed KPI were represented through the calculation of cumulative values of external ppm for each single month, as per the formula (1). In Graph 1, the graphical representation illustrates the total amount of delivered parts alongside the trend of EXT-ppm for parts that had defect for each month throughout the year 2022.

Observing Graph 1, it can be deduced that the EXT-ppm values for each month in 2022 vary within the range of 30 to 105. The established target value for external ppm in the analyzedenterprise was determined in alignment with the enterprise's quality objectives for the year 2022, aiming to ensure that the external ppm will stay under 300 ppm. The presented results indicate that the achieved values of EXTppm are lower than the threshold target values, which is a favorable situation for evaluation. In terms of the quality of delivered parts for customers, it can be stated that customer complaints constitute less than 0.03% of the order volume.



***Graph 1** Evaluating the quantity of delivered units and the progression of external parts per million (EXT-ppm) for defective units in 2022*

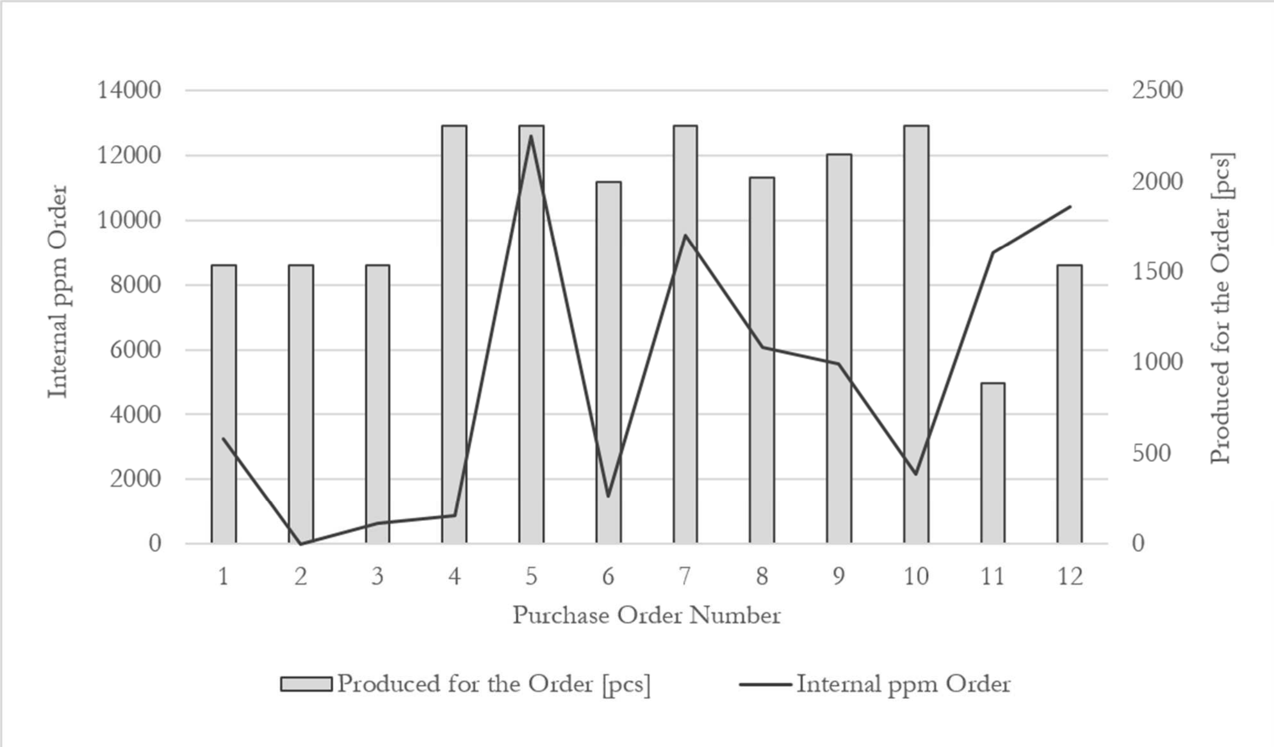
3.2 KPI evaluation - number of non-conforming products via INTppm

The productivity of orders of part A was analyzed and evaluated according to the count of non-conforming units during the duration of the order in the 2022. The result is the expression of the internal ppm for the given part A for individual orders (Tab. 2). There is always evaluated the period of production of a specific order after its completion. The inputs are the count of manufactured products per order and the count of non-conforming products created during a specific order. The INTppm indicator (2) is an expression of the overall stability of production for the period of a specific order for the given evaluated period.

***Tab. 2** Productivity evaluation of Part A orders using INTppm for the evaluated period*

Purchase Order Number	Order Completion	The total volume of manufactured parts A in the order Vc [pcs]	Volume of non-conforming parts A in the order Vn [pcs]	Internal ppm INTppm [-]
1	3.1.2022	1536	5	3255
2	27.1. 2022	1536	0	0
3	24.2. 2022	1536	1	651
4	9.3. 2022	2304	2	868
5	21.4.2022	2304	29	12587
6	28.6.2022	2000	3	1500
7	21.7. 2022	2304	22	9549
8	1.8. 2022	2022	14	6076
9	9.9. 2022	2152	12	5576
10	10.10. 2022	2304	5	2170
11	7.11. 2022	890	8	8989
12	19.12. 2022	1536	16	10417

The graph (see in Graph 2) shows graphically processed values from the table (see in Tab. 1). The graph presents a mutual comparison of the count of manufactured units per order and the internal ppm per order.



***Graph 2** Graphical evaluation of performance of Part A orders using internal ppm INTppm in 2022*

When evaluating the results shown in the graph, see in Graph 2, we can state that the INTppm values have a very fluctuating tendency, which expresses the instability of the evaluated process. The target value for the evaluated KPI is the value of the total internal ppm, which was set in the company's quality objectives for two consecutive years (2022 and 2023) at a maximum value of 2000 ppm. The target value of INTppm is therefore the achievement of a maximum value of 2000 ppm for individual evaluated orders for part A. The achieved average value for individual orders of part A during the monitored period was 5136.5 ppm, which means that the enterprise's goals in the area of quality and process performance for the given order were not achieved.

3.3 Discussion

Implementing key performance indicators (KPIs) in a production firm is a complex and prolonged method. A crucial factor for the management leading to succes of this method is the support from top management, senior staff, and the employees directly involved in the places associated with the established KPIs. Monitoring KPIs establishes a systematic approach for the organization to identify and establish operational goals aimed at ensuring and enhancing process performance [20].

For engineering companies, a primary advantage of KPI implementation lies in the ability to analyze individual processes comprehensively, moving beyond a purely financial perspective [21]. Through KPI implementation, every enterprise gains an analytical tool that quantifies process performance in relation to specified goals, ultimately stabilizing the quality and reliability of its processes and aligning with standard requirements.

The implementation of the key indicators of the performance of production processes and the determination of the values of the measured indicators was carried out according to the proposed procedure in the previous published article [22].

When analyzing the efficiency of manufacturing processes, qualitative indicators evaluating the ratio of defective/faulty products to the production volume were used as Key Performance Indicators (KPIs). Specifically, non-conforming products identified by the customer (EXTppm) and non-conforming products detected during control processes in production (INTppm) were evaluated. For the exact expression of the KPI were created proportional indicators which express the cumulative number of non-conformities per month in proportion to the cumulative volume of products delivered/produced in a period per month.

From the point of view of external ppm evaluation, we can state that the achieved EXTppm values are lower than the limit target values of the enterprise (300 ppm), which is a positive finding for the year 2022. Compared to the previous years 2020 and 2021, where EXTppm culminated or even exceeded the limit of 300 ppm, the evaluated parameter improved. During the pandemic in 2020 and 2021, the enterprise faced an unfavorable trend in the count of customer complaints. So it was necessary to take several measures to stop this negative direction. The best measurement in terms of efficiency contained:

- Focusing on Process Quality and Machine Reliability: Giving significant attention to the quality of processes and the safety of machines.
- The introduction of random checks of single products in the order of 10 %: Introducing a random inspection of single products from each laborer at the end of their shift.
- Briefing for New Employees: Providing mentoring for new employees to ensure a smooth integration into the workforce.
- Creating a Education Plan with Skill and Knowledge Checkpoints: Developing a training plan with checkpoints to assess the acquired skills and knowledge.
- Stabilizing the Workforce Team: Taking steps to stabilize the workforce team, possibly through measures aimed at improving morale, communication, or addressing any internal issues.

These measures were put in place to address and mitigate the challenges posed by the adverse developments in customer complaints, particularly during the challenging circumstances of the pandemic years. From the analysis of internal ppm and its high values, where compared to the target value of 2000 ppm, average values of 5136.5 ppm were achieved in 2022, we can conclude that the production processes were not efficient and produced a high number of non-conforming products. When evaluating the causes of non-conforming products, the enterprise identified the most frequently recurring reasons for non-conformities:

- Clamping error – short, mismatched units were produced;
- Worn cutting plate, need to replace the cutting plate - damaged units were created.

Based on previous findings, the enterprise took measures to improve the unfavorable situation. As a solution to eliminate the causes of clamping error during turning, the technologist proposed modifications to the clamping mechanism, changing the stop, and re-turning the soft jaws of the chuck. The stop against which the part rests at one point during clamping needs to be adjusted so that the part rests at several points, thereby is eliminated the possibility of the part being crookedly clamped in the chuck. Eliminating the cause of a worn cutting insert and timely replacement of the cutting insert in the turning operation is a matter of appropriate diagnosis of the problem and maintenance of the machine. Prescribing a suitable interval for replacing the cutting plate is the prevention of the wear of the cutting plate and thus the creation of a faulty unit.

The analyzed enterprise pays great attention to the solution to the removal of non-conforming products, primarily due to the satisfaction of customer requirements, the removal of any complaints, and last but not least, the improvement of economic indicators. From the comparison of external and internal ppm, we can conclude that even though a relatively high proportion of non-conforming products in production was revealed, the faulty products mostly did not reach customers, which documents a favorable state in external ppm.

4 Conclusion

The research introduced in the paper aimed to offer a way of implementing key indicators for assessing the performance of manufacturing processes and determining the size of these indicators.

The research was aimed to evaluating the performance of production processes using indicators characterizing product quality. Two KPIs were selected for the analysis and evaluation of the efficiency of production processes in the analyzed enterprise based on qualitative indicators: the count of complaints, representing non-conforming products identified by the customer and the count of non-conforming products, which presented non-conformities detected during control processes in production. For the exact calculation of the KPI, ratio indicators EXTppm and INTppm were proposed, which express the cumulative number of non-conformity per month in proportion to the cumulative volume of products delivered/produced in a period per month. The article presents the results of the evaluation of the mentioned indicators during one calendar year. The results show that while the EXTppm indicator reached favourable values, not exceeding the quality targets, the INTppm values were higher than the specified ppm target values. The evaluated enterprise have taken several measures to improve the current situation and will continue to monitor KPIs based on the created procedures.

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