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ANALYSIS OF THE EXTERIOR DOOR PRODUCTION PROCESS USING KEY PERFORMANCE INDICATORS (KPI)

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Abstract
Due to the constantly increasing demands of customers and global competition, companies are forced to look for production reserves, increase efficiency and quality of manufactured products. Hence the need to monitor the quality level, which gives the possibility to recognize waste in the implemented technological processes. The article is an attempt to respond to the problems formulated in manufacturing companies, including practical aspects of the application of Key Performance Indicators (KPI) within production process controlling. The aim of the article is to determine the impact of the applied quality management techniques on selected KPI indicators in the production process of frame and panel exterior doors. As part of the study, an analysis of the reasons for the decrease in the level of quality indicators was performed using traditional quality management tools.

Keywords
Key Performance Indicators (KPIS), Pareto-Lorenzo Diagram, ABC Method, Ishikawa Diagram, production management, production engineering.

1. Introduction

A high level of product quality requires constant process monitoring, analysis and improvement. Continuous monitoring of the production process involves the recording and collection of accurate data on its progress. This type of action is an important element of the company management strategy [10, 21, 25]. This task can be carried out both manually, by filling in the relevant datasheets or forms, and electronically, for example by using MES – Manufacturing Execution Systems [3, 11]. However, to perform process analyses, it may be difficult to coordinate the use of raw measurements with different specifications and additionally from many working positions. It is much more practical to use numerical indicators of a synthetic nature, which combine data from various sources. For this purpose, so-called Key Performance Indicators (KPI) are used in production systems. KPIs are defined as a set of measures (metrics) used to facilitate the assessment of production system performance from the perspective of performance, quality and maintenance [6, 9]. However, these indicators are numerous (over 100) and calculating all of them seems pointless. In practice, companies use several or more [8, 15, 18–20]. The indicators allow to assess the production system in terms of quality but to maintain the desired level of quality, tools and methods are used such as quality management among other things. They make it possible to identify both the causes of problems and solutions to improve the quality of products [28, 29].

The purpose of the article is to determine the impact of the quality management techniques used on selected KPIs in the framework-sequenced process of exterior door production. The study identified the reasons for deviations from the planned level of product quality. Selected quality management techniques were used for this purpose.

2. Characteristics of KPIs

The methodology for the application of the measures in management, which combines both processes controlling and Lean Manufacturing tools, is the concept of key performance indicators (KPI). The idea of using key indicators is based on rationalization and selection of an appropriate profile of indicators to facilitate the measurement of the achievement of objectives, defined by the SMART concept (Specific, Measurable, Achievable, Relevant, Time-bound) [12, 23, 27, 35]. Proper selection of indicators is of key importance because not everything that can be measured is equally important for improving knowledge and then drawing the right conclusions. From the range of indicators available, several or more [4, 32, 33] should be selected, which best reflect the level of achievement of strategic objectives [2]. The KPI aims to measure the level of implementation of the planned actions and, at the same time, to address problems and risks by identifying them, then minimizing or eliminating them [1, 5, 13, 14, 24, 30, 34]. KPIs are used to measure the parameters that are fundamental from the economic, technical and organizational point of view, which characterize the functioning of an enterprise, and allow not only to determine the value of applied KPIs but also to identify selected factors influencing their values [4, 16].

Key Performance Indicators are characterized by a hierarchical structure and the related internal interrelationships. Three levels of indicators can be specified: direct, basic and complex. Direct indicators can be broken down according to the quantities that are related to time (e.g. actual and planned operating time of the device) and quantitative measurements taking into account e.g. the actual and planned number of products manufactured. The basic indicators concern the quality of manufactured products, the efficiency of the production system and its maintenance. This group of indicators can be divided into indicators necessary to determine complex indicators and indicators relating to important production process parameters. Core indicator values are calculated based on core indicators. By contrast, composite indicators provide a synthetic measure of the performance of a production process in terms of machine and human resource efficiency. The collection of appropriate values for direct and primary indicators is necessary to calculate composite indicators [4].

Among the often used quantitative, direct indicators, one can mention measurement of the number and quality of manufactured products [17]:

- number of products meeting the quality requirements,
- number of non-compliant but recyclable products,
- number of products not meeting the quality requirements,
- total number of products manufactured (PQ Processed Quantity), calculated according to the formula:

$$\mathrm{PQ} = \mathrm{GQ} + \mathrm{RQ} + \mathrm{SQ}, \tag{1}$$

  where GQ (Good Quantity) – number of products meeting the quality requirements, RQ (Rework Quantity) – number of products not satisfying the requirements but recyclable, SQ (Scrap Quantity) – number of products not meeting the quality requirements.

On the basis of the direct indicators mentioned above, it is possible, in the next stage, to determine basic and complex KPIs which are of interest to production engineers and managers of the company.

Another group are the basic KPIs whose values are calculated on the basis of direct indicators. Among the frequently used basic KPIs describing the quality characteristics of products, one can mention, among others [17]:

- the percentage of good quality products QR (Quality Ratio), being the total percentage of good quality products produced, calculated according to the formula:

$$\mathrm{QR} = \frac{\mathrm{GQ}}{\mathrm{PQ}}, \tag{2}$$

  where GQ (Good Quantity) – number of products meeting the quality requirements, PQ (Processed Quantity) – total number of products manufactured;
- the percentage of good quality marketable products QBR (Quality Buy Rate), i.e. the total percentage of good quality products including reprocessed elements, calculated according to the formula:

$$\mathrm{QBR} = \frac{\mathrm{GQ} + \mathrm{RQ}}{\mathrm{PQ}}, \tag{3}$$

  where GQ (Good Quantity) – number of products meeting the quality requirements, RQ (Rework Quantity) – number of products not satisfying the requirements but recyclable, PQ (Processed Quantity) – total number of products manufactured;
- the percentage of conformity of the production quantity (of good quality products) with the production plan (for the purpose of elaboration marked as WJ) calculated according to the formula:

$$\mathrm{WJ} = \frac{\mathrm{SPQ} - \mathrm{SQ}}{\mathrm{SPQ}}, \tag{4}$$

  where SPQ (Scheduled Production Quantity) – planned number of manufactured products meeting quality requirements, SQ (Scrap Quantity) – number of products not meeting the quality requirements;
- the percentage of quantitative deviations in the manufacturing process of products (for the purpose of elaboration marked as IO) calculated according to the formula:

$$\mathrm{WI} = \frac{\mathrm{PQ}}{\mathrm{SPQ}}, \tag{5}$$

  where PQ (Processed Quantity) – total number of products manufactured, SPQ (Scheduled Production Quantity) – planned number of manufactured products meeting quality requirements.

Providing reliable feedback on the tasks performed in the form of direct and basic KPIs enables decision-makers to quickly identify sensitive areas or failures in the company and further analyze the situation and implement remedial actions [31]. These indicators are thus defined as key measures of an organization's performance and as tools to help technical staff to ensure the appropriate level of quality, performance of equipment and infrastructure [7, 26].

3. The object and the scope of research

The research was carried out in the production company Agmar, which offers wooden exterior and internal interior doors, frames and a wide range of door accessories. The company is located in south-eastern Poland. The subject of the tests was frame-and-panel exterior doors (Fig. 1). Due to a significant decrease in quality in the form of an increase in production of non-compliant products and complaints from customers concerning

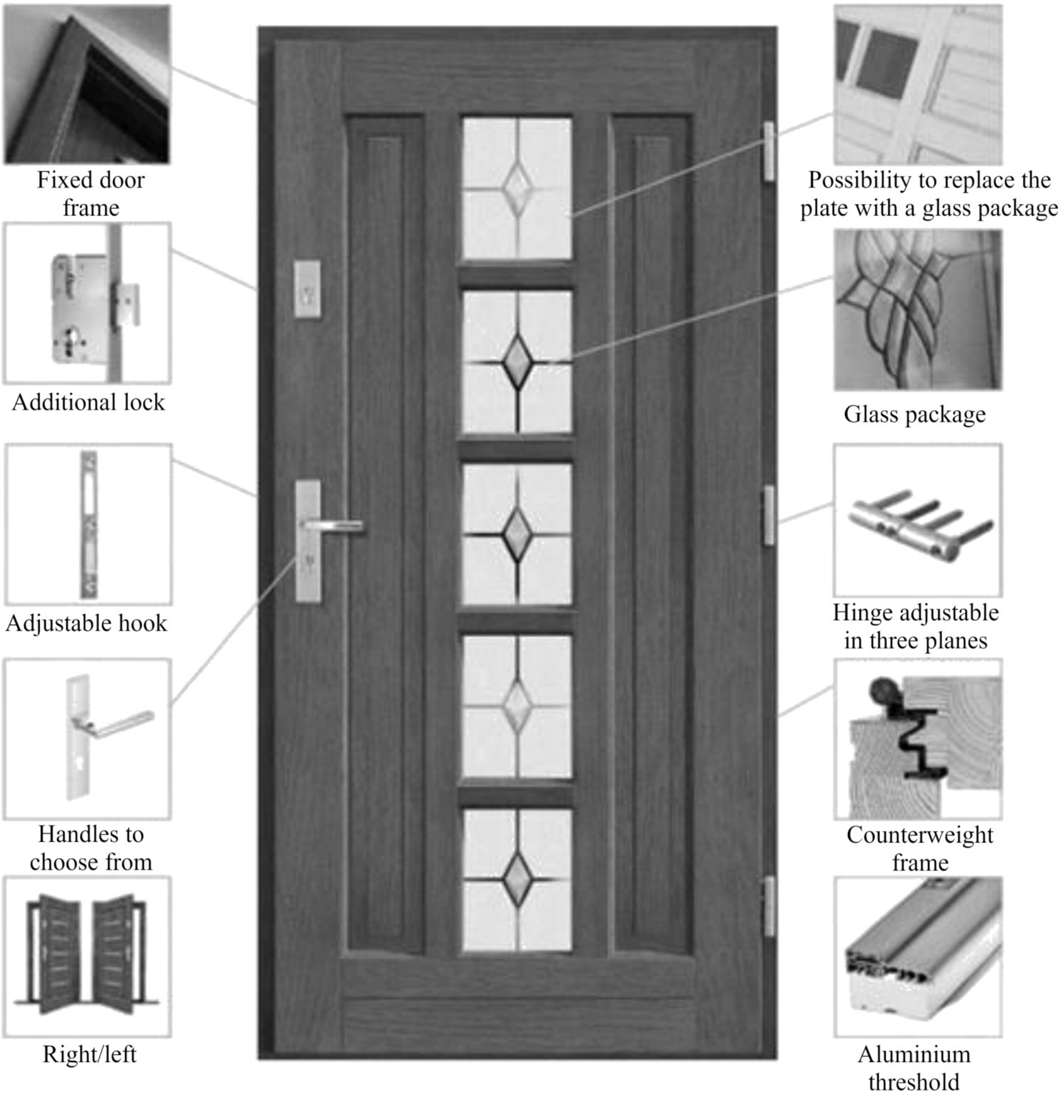

Fig. 1. Model of the test subject together with its components [22].

frame-and-panel exterior doors, it was decided to analyze the problem. The level of non-compliant products in two months reached 9% of all products produced. Therefore, the analysis was carried out for batches of products made in the 1st and 2nd quarter of 2019.

4. Methodology of research

The methodology of the undertaken research included index analysis of the production process using qualitative KPIs to monitor the production process and the use of quality management tools to identify the causes of deviations from the planned level of product quality. To measure the quality efficiency of the process, the frequently used indicator of the total number of manufactured products (PQ), good quality products (QR), good quality products including reprocessed elements (QBR), compliance of the number of products with the production plan (JP) and the indicator of quantitative deviations in the process of manufacturing products were used (WI). As part of the implementation of the batch defect analysis, the Pareto-Lorenz diagram combined with the ABC method was used to identify the most significant inconsistencies in terms of their number and their effects. Besides, the analysis of the causes of product non-compliance included the use of the Ishikawa diagram to identify potential causes of the problem. The research included a qualitative analysis of the production process using the KPIs presented in the study. Figure 2 shows the total number of manufactured products (PQ index) in Q2 and Q3 2019 divided into several products meeting the quality requirements (GQ), number of products not meeting the requirements but recyclable (RQ) and number of products not meeting the quality requirements (SQ).

Figure 3 shows the indicators selected by the authors and used in the company, i.e.: percentage of products reaching the desired quality level (QR) percentage of products reaching the desired quality level including recycled elements. (QBR), the percentage of conformity of production quantities (QJ) and the percentage of quantitative deviations in the manufacturing process (QI).

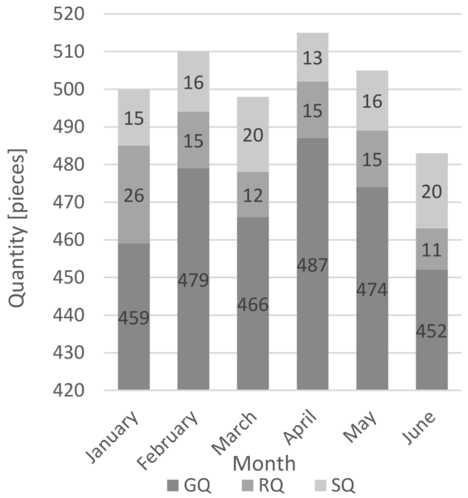

Fig. 2. Stratified production volume of exterior doors of the frame-panel type in the 1st and 2nd quarters [22].

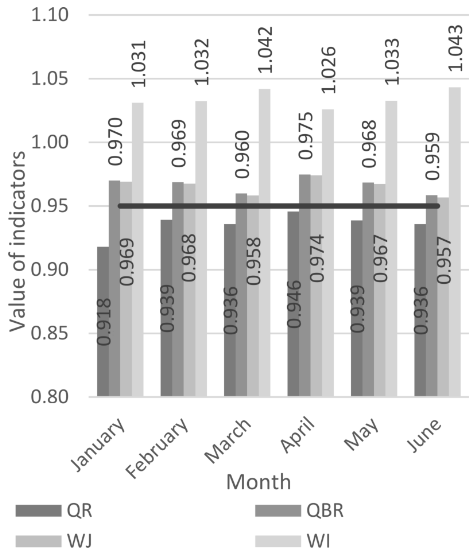

Fig. 3. Quality indicator values within the time frame analyzed [22].

The current qualitative target of the company concerning the quality level of manufactured products (QR index) is 0.95. Based on Fig. 3, it can be seen that the QBR indicator did not reach a fixed value during the period under examination. The QBR index taking into account the number of reprocessed products reaches values above 0.95, however, it should be remembered that reprocessing (repair) of products generates additional costs. Therefore, this result should not be interpreted as not requiring adjustment. The values of WJ index in the period under examination reach the values slightly lower than the values of QBR index. It is worth noting that any discrepancy between the number of finished products (which are consistent in quality) and the production plan is interpreted as an error, i.e., that both values below and above indication 1,0 for the WI indicate an error. An error should be understood as not only missing figures concerning the plan but also those supplied in excess. Due to the presence of noncompliant products, to meet customers' requirements, the company is forced to produce more products than planned. To obtain higher values for the QR indicator, it is necessary to identify sources of quality problems, determine their importance and gradually eliminate or reduce them. The compilation of complaints conducted in the company in the analyzed period implies that the most frequent reason for complaints is production defects.

The proposed instrument for analyzing product defects was the Pareto-Lorenzo analysis combined with the ABC method, whose aim was to identify the most significant discrepancies in terms of their number (Fig. 4).

The nonconformities in the product under investigation presented in the diagram are marked (as in the company) successively: 1 – glue leaks between layers of veneer, 2 – air bubbles under the painted surface, 3 – unsuitable slide lock installation, 4 – unsuitable hinges installation (jamming), 5 – non-adhesion of gaskets to the surface, 6 – too much space in the counterbalance rebate, 7 – unsuitable handle installation, 8 – paint leaks, 9 – unsuitable threshold selection. Analysis of the product showed that the most important incompatibilities are adhesive leaks between layers of veneer (48.1%) and air bubbles under the painted surface (33.1%). These discrepancies account for 81.2% of all deficiencies. According to the ABC method, the area A to which the non-compliances are qualified is determined as critical The second stage of the product defect analysis is the analysis of potential causes of occurrence of the most significant non-compliance. Analyzing the problem, a working group was gathered, consisting of the following employees: quality control manager, quality control employee, production manager and employee accepting complaints from customers. The "brainstorming" session to support the development of the Ishikawa diagram resulted in listing the root causes within the 5M+E areas of the Ishikawa diagram (Fig. 5). The study analyzed the type of noncompliance that was found to be predominant in terms of quantity and impact: non-compliance concerning adhesive leaks between layers of veneer. Factors influencing the formation of incompatibilities in the finished product were distinguished in the area of "material" – application of glue of inadequate quality and in the area of "environment" – abnormal atmospheric conditions inside the production hall - excessively high air humidity. The incorrect level of air humidity reduced the viscosity parameter of the glue batch located on the veneer gluing workstation. In combination, these variables contributed to the application of the wrong amount of glue. The implementation of corrective actions (normalizing the level of humidity in the production hall) and preventive actions (conducting constant monitoring of the level of humidity and temperature in the production hall and the warehouse, constant monitoring of the quality of glue carried out by employees at the veneer gluing station and conducting training for employees on workstations) was realized in the 3rd quarter of 2019.

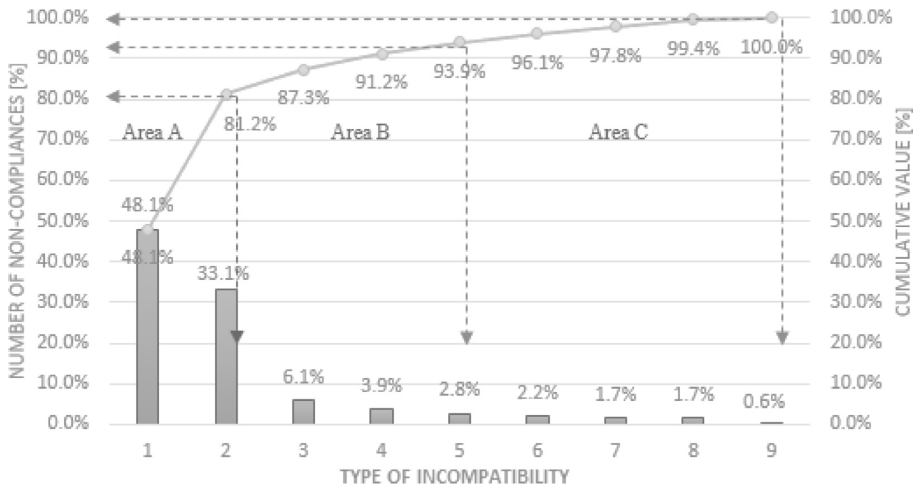

Fig. 4. Pareto Lorenzo diagram with ABC method for exterior door incompatibility.

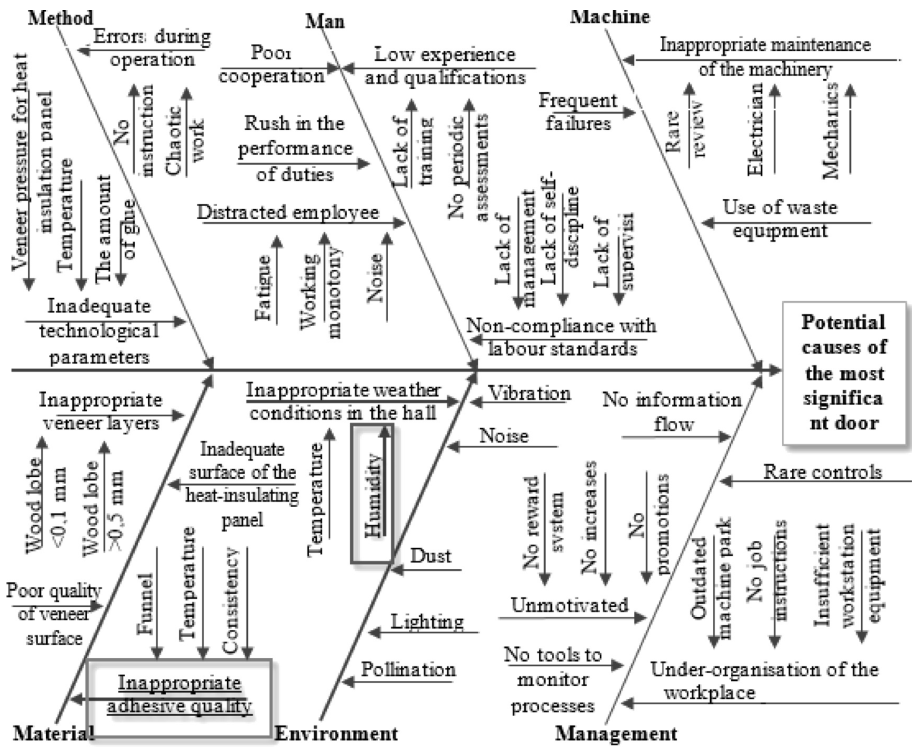

Fig. 5. Potential causes of adhesive leakage between veneer layers.

As part of checking the effectiveness of the actions taken after the end of the 4th quarter, the necessary data were collected from the quality lists and complaints conducted in the company and a summary was prepared to present the total number of manufactured products (PQ) with a division into several products meeting the quality requirements (GQ), number of products not meeting the requirements but possible to be reprocessed (RQ), and number of products not meeting the quality requirements (SQ) (Fig. 6).

According to Fig. 6, in Q4, we can observe an increase in the quality of the offered products (increase in the GQ value, decrease in the Q1 and Q2 value) concerning Q1 and Q2 (Fig. 2). Figure 7 presents the values of the indicators used in the company selected by the authors (percentage of products reaching the desired quality level (QR), percentage of products with the desired quality level taking into account recycled elements (QBR), percentage of conformity of production quantity (JU) and percentage of quantitative deviations in the production process (I) in Q4 2019. Based on the obtained values of qualitative indicators, it can be concluded that the assumed qualitative goal has been achieved. The qualitative objective concerning the key QR indicator (exceeding the value of 0.95) was achieved, and its values in the 4th quarter were 0.966, 0.973 and 0.975, respectively, which proves the accuracy and effectiveness of the undertaken countermeasures.

As part of further improvement of the quality level of products in the company, the remedial actions taken should be continued and the processes implemented in the company should be constantly monitored.

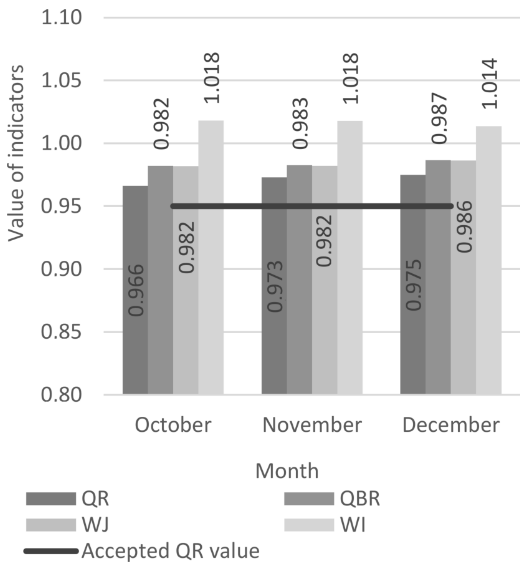

Fig. 6. Stratified production volume of exterior doors of the frame-panel type in the 4th quarter [22].

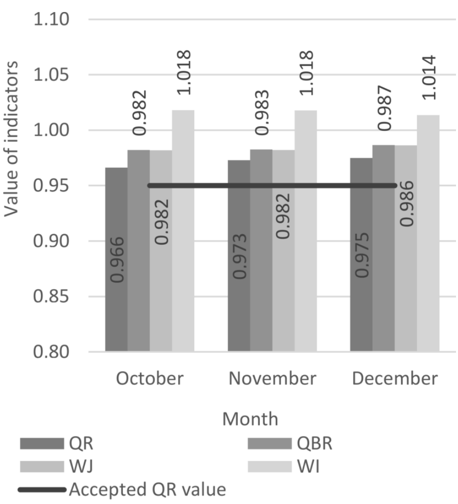

Fig. 7. Stratified production volume of exterior doors of the frame-panel type [22].

5. Conclusions

Properly selected indicators are a key element in the proper use of controlling in an organization. Key Performance Indicators (KPIs) used in a manufacturing company require their inclusion in the structure and management system of the company. Monitoring of the production process through the use of indicators is a tool that helps to control the organization and indicates the emergence of problems in the company, thus enabling a dynamic response and documentation of actions and effects.

The selected indicators of production process monitoring used in the analyzed company, presented in the study, fulfil their basic functions, enabling the tracking of the production process in the area of quality of offered products and production planning and control. Thus, they are indicative of the level of fulfilment of the assumed quality objectives in the company. The key indicator for a company is the percentage of good quality products (QR) against which quality objectives are set. The company's current target for the quality level of its products (QR index) is 0.95. Based on the survey, it can be seen that the QBR indicator in the examined period does not reach the established value. For this reason, it is important that the door leaf is made correctly and thus passes through all stages of the technological process. Most often during the production of frame-and-panel exterior doors, there are product incompatibilities caused by production defects, as a result of which complaints for some of the doors are lodged by customers due to adhesive leaks between layers of veneer. So far, in the area of improvement of the existing problem in the company, no quality management tools have been used to solve production problems.

The quality management tools used in the study contributed to the identification of the most significant nonconformities (adhesive leaks between the layers of veneer) and to the identification of potential causes of product quality deterioration (inappropriate level of air humidity, which reduced the viscosity parameter of the glue batch, which made it much more difficult to apply the appropriate amount of glue). An analysis of the quality problem will make it possible to implement appropriate corrective and preventive measures, thus contributing to the achievement of the desired objectives for the company.

To significantly reduce the occurrence of incompatibilities arising during the production process of exterior doors, decision was taken to regularly inspect the materials used in the production of the product and control the air conditions inside the production hall and warehouse. Besides, the employees' qualifications are ensured through further training courses and periodic employee assessments. The countermeasures taken have proved effective.

The company has significantly increased the quality of its products. The presented sequence of examining the existing quality problem with the use of selected key effectiveness indicators and traditional methods of quality management is a universal and effective way of analyzing production problems which can be practiced in companies from different production branches.

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