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ANALYSIS AND IMPROVEMENT OF THE PRODUCTION SYSTEM IN PRODUCTION ENTERPRISE

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Purpose: The aim was to analyze inconsistencies in the production process of rebated internal frame and panel doors using KPIs and to identify causes of deviations from the quality plan using selected quality management tools**.**
Design/methodology/approach: KPIs and instruments of quality management (Pareto-Lorenz diagram, Ishikawa diagram and 5Why?) were used. The survey covered products manufactured in the third and fourth quarters of 2019.
Findings: It was found that the most serious non-compliance was the presence of an uneven rim surface (Pareto-Lorenz diagram). Potential causes were inadequate gluing of the door leaf layers and the use of worn flange processing equipment (Ishikawa diagram). On the other hand, the root cause of the quality problem turned out to be the lack of supervision and proper training of employees (5Why method).
Research limitations/implications: The presented research process has no limitations – it can be used in manufacturing companies. Further research will concern the application of the methodology to the analysis of other products offered by the company.
Practical implications: the research contributed to the identification of the causes of the lowered quality level, which will allow to implement appropriate remedial measures. As part of the improvement measures, training must be carried out at the workplace and the availability of work instructions must be ensured.
Originality/value: so far no extended quality analyses have been conducted in the company – no KPIs have been used in combination with extended analyses carried out with the use of quality management tools. The presented methodology is useful for the company where the analysis was made and for the manufacturing companies that want to effectively improve their production processes.

Keywords: mechanical engineering, quality engineering, key performance indicators (KPIs), quality management tools, manufacturing process.

Category of the paper: research paper and case study.

1. Introduction

Dynamically progressing changes in the world economy force manufacturing enterprises to permanently improve their functioning both in the aspect of management and in the production plane (Wolniak, and Skotnicka-Zasadzień, 2010; Pacana, and Czerwińska, 2017). Reorganisation, modernisation, as well as ISO standardisation (having an impact on innovativeness), are phenomena commonly occurring in production enterprises, which contribute to the increase of the effectiveness of their functioning, as well as undertaking actions compliant with the concept of sustainable development. These phenomena constitute a continuous and inevitable process of the progressive character (Mentel, Hajduk-Stelmachowicz, 2020; Hajduk-Stelmachowicz, 2014). According to the requirements of the modern market, the production process should meet the requirements related to the efficiency and flexibility of manufacturing. Such a modernly organized production process can efficiently react to: internal variability and implementation of new start-ups as well as external variability and competitive pressure. A response to such requirements is the creation and development of flexible production systems combining the diversity of production assortments (achieved in the non-rhythmic production system – production cells) and high efficiency and effectiveness (achieved in the rhythmic production system – production line automation) (Brzeziński, 2013; Krzyżanowski, 2005).

An important issue within the mature management of flexible manufacturing systems is the exercise of control in the manufacturing process which creates the opportunity to identify important manufacturing issues (Grabowska, and Hamrol, 2016; Wolniak, 2011). In the course of process analysis, it is crucial to use synthetic indicators that capture data from various sources. Key Performance Indicators (KPIs) work well for this purpose. KPIs are defined as a set of measures aimed at assessing the performance of a production system in terms of its quality, efficiency and maintenance (Bornos et al., 2016; Holender et al., 2016; Cheng, 2011). These indicators, allow to evaluate and monitor the functioning of the production system (Grabowska, 2017; Grycuk, 2010), however, to maintain the desired level of quality and solve production problems, quality management methods and tools should be applied (Czerwińska et al., 2020; Pacana, and Czerwińska, 2018; Sułkowski, and Wolniak, 2013; Wolniak, and Skotnicka, 2008).

The study aimed to perform an analysis of critical areas in the production process of rebated internal frame and panel doors with the use of key performance indicators (KPIs) and identification of causes of deviations from the quality plan using selected quality management tools. The study also focuses on the organizational activities of the company and the search for opportunities to improve the current state and conduct continuous improvement.

2. Characteristics of key performance indicators (KPIs)

The methodology for the application of measures in management, which combines both process controlling and Lean Manufacturing tools, is the concept of key performance indicators (KPIs). The idea of using key indicators is based on rationalisation and selection of an appropriate profile of indicators to facilitate the measurement of the achievement of objectives, defined in accordance with the SMART concept. (Specific, Measurable, Achievable, Relevant, Time-bound) (Mourtzis, 2018; Podgórski, 2015; Zhou, and He, 2018).

Key performance measures (KPIs) help businesses understand how well they are performing against their strategic objectives. In the broadest sense, a key performance measure provides the most important information about performance that enables companies or their stakeholders to know whether the organization is on the right track. Key performance measures are used to simplify organizational characteristics into a small number of key metrics to increase organizational effectiveness (Marr, 2010; Kang et al., 2015; Barone et al., 2011). From the range of available indicators, one should select a few or several that best reflect the level of achievement of strategic objectives (Emiliani et al., 2003). Among the frequently used quantitative indicators we can mention the measurement of the number of products meeting the quality requirements (Good Quantity – GQ), the measurement of the number of products not meeting the requirements but possible to be reprocessed (Rework Quantity – RQ), the measurement of the number of products not meeting the quality requirements and impossible to reprocess (Scrap Quantity – SQ) and the measurement of the total number of manufactured products (Processed Quantity – PQ). The parameter PQ is calculated as the sum of the parameters GQ, RQ and SQ (International Standard ISO 22400-2 2014).

With the help of direct KPIs, it is possible to determine basic and composite indicators. The basic KPIs describing the quality characteristics of products are presented in Table 1 (Sułkowski, and Wolniak, 2013):

Indicators are a reference point for employees, as they reflect the current characteristics of processes, facilitate rules of cooperation that are clearly defined and accepted by all parties. Introduction of indicators is related to building an adequate motivation system, which should be linked to the achieved results (Grycuk, 2010).

Table 1.
Basic KPIs describing quality features of products

No	Indicators KPI	
	Description	**Pattern**
1.	total number of manufactured products (Processed Quantity – PQ)	$PQ = GQ + RQ + SQ$
2.	percentage of good quality products QR (Quality Ratio), which is the overall percentage of good quality products manufactured	$QR = \frac{GQ}{PQ}$
3.	percentage of good-quality goods fit for sale QBR (Quality Buy Rate), i.e. the overall percentage of goods of good quality along with elements of recycled products	$QBR = \frac{GQ + RQ}{PQ}$
4.	percentage of compliance of the quantity of products (good-quality products) with the production plan (defined as WJ for the purposes of the development)	$WJ = \frac{SPQ - SQ}{SPQ}$
5.	percentage of quantitative deviations in the product manufacturing process (defined as IP for the purposes of the development)	$WI = \frac{PQ}{SPQ}$

Note. International Standard ISO 22400-2 2014.

3. Subject and scope of research

The research was conducted in the Agmar company, whose product range includes wooden interior and exterior doors with frames and a wide range of door accessories. The company headquarters is located in the south-eastern part of Poland. So far the company has not used KPIs in combination with extensive analyses performed with the use of quality management tools.

The object of research was rebated interior door with the panel, which standard equipment includes: leaf thickness 40 mm, fixed frame with dimensions 105 mm x 60 mm, the gasket on the perimeter of the frame, glued milk glass or transparent, one lock (key, insert), two hinges adjustable in three planes and hinge covers. The doors are finished by varnishing in a four layer system using a hydrodynamic method with transparent paints.

In view of the significant reduction in the level of quality and an increase in the number of complaints about internal doors, it was decided to analyse the problem. The analysis covered batches of products manufactured in Q3 and Q4 2019.

4. Research methodology

The research methodology included an indicator-based analysis of the manufacturing process of rebated internal doors with the use of qualitative KPIs within the framework of supervising the process quality level and the implication of quality management tools in order to identify the causes of quality deviations (Figure 1).

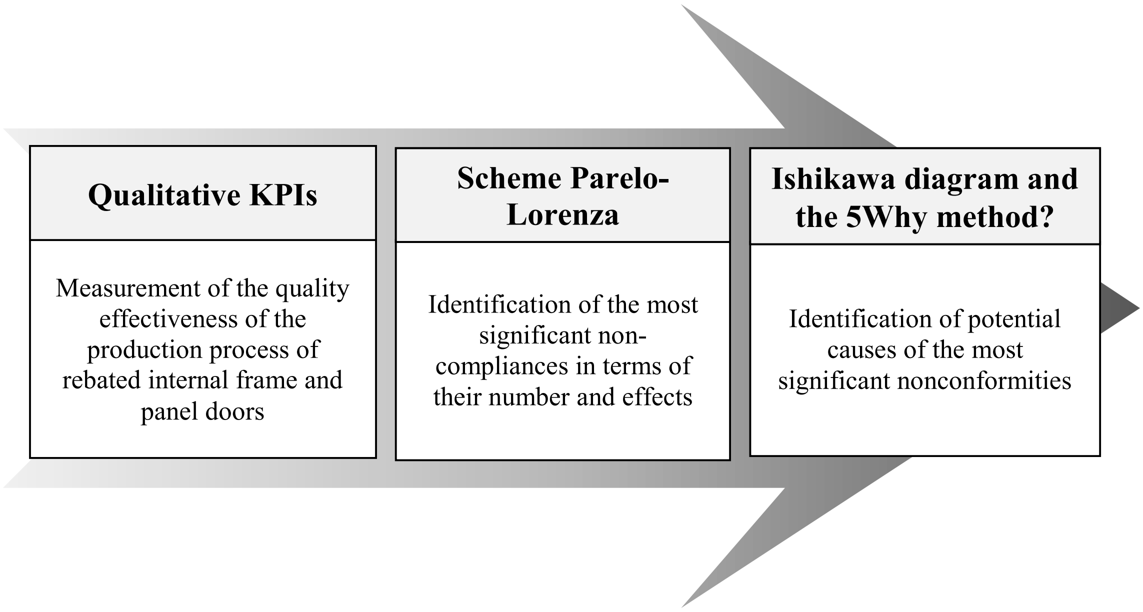

Figure 1. Methodology of studies used to analyse non-compliances and identify their causes

In order to diagnose the level of the qualitative efficiency of the process, the following indices were used: number of manufactured products (PQ), number of good quality products (QR), number of good quality products including elements reworked (QBR), compliance of the production quantity with the production plan (WJ) and the index of quantitative deviations in the process of manufacturing products (WI).

The analysis of the defectiveness of the product batches was carried out using the Pareto-Lorenz diagram, the cause-effect diagram and the 5Why? The Pareto-Lorenz diagram was used to identify the most significant inconsistencies in terms of the number of occurrences and their consequences, while the cause-effect diagram and the 5Why? were used to identify the potential causes of the most serious non-compliances.

5. Research results and analysis

A qualitative analysis of the production process was performed using the KPIs presented in the paper. The total number of manufactured products – indicator PQ, in the period considered is shown in Figure 2. The graphic includes a breakdown into: products that meet quality requirements (GQ), products that do not meet quality requirements but can be reprocessed (RQ), and products that do not meet quality requirements and cannot be repaired (SQ).

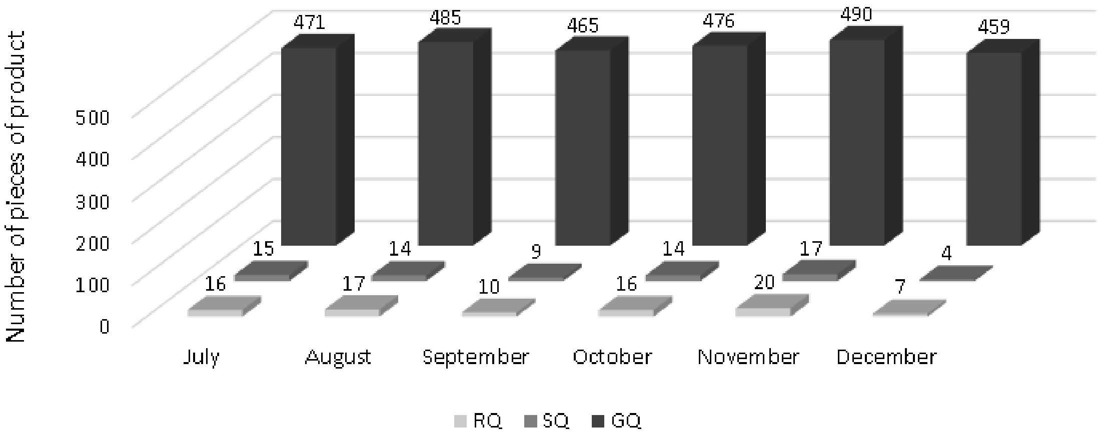

Figure 2. Production volume of the tested product. Source: Own elaboration based on: Agmar Door materials. Unpublished materials. Chwałowice, 2019.

Based on figure 2 it can be seen that the sum of all the nonconforming products manufactured amounted to 159 pieces, which constituted 5% of all the produced door panels. The highest number of nonconforming products was manufactured in November (37 pieces, 46% of which were not repaired), while the lowest number of nonconforming products was manufactured in December (9 pieces, 36% of which were not repaired). It may be assumed that the relatively low values for non-compliant products in December are influenced by the decrease in the total number of products manufactured.

Figure 3 shows the values of the indicators used in the study: the percentage of products achieving the desired quality level (QR) the percentage of products with the desired quality level including reprocessed elements (QBR), the percentage of conformity of production quantities (WJ) and the percentage of quantity deviations in the manufacturing process of products (WI).

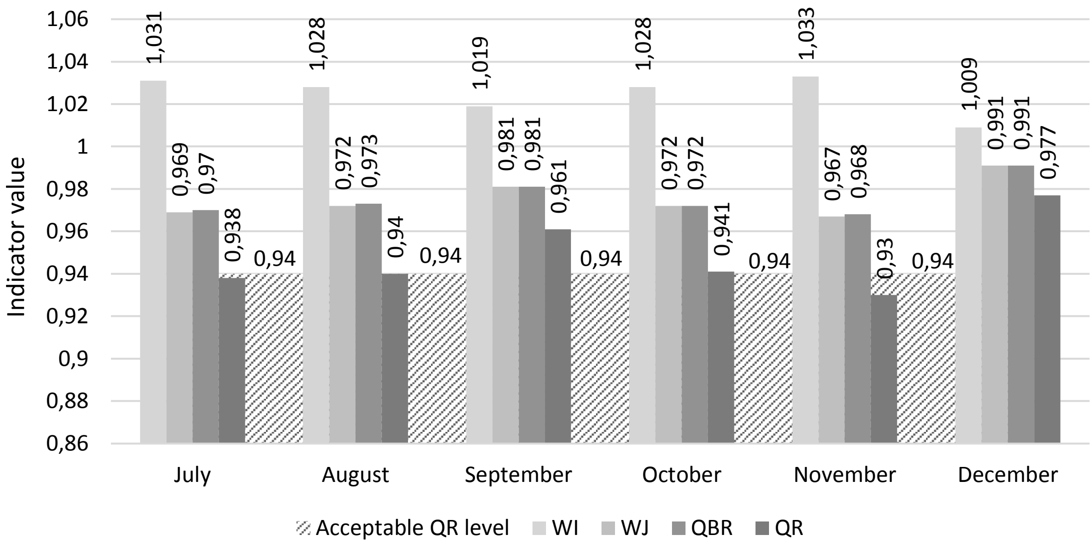

Figure 3. Values of qualitative indicators. Source: Own elaboration based on: Agmar Door materials. Unpublished materials. Chwałowice, 2019.

WJ index values are equal or slightly lower than QBR index values. The WI values also deviate from the assumed values, as its desired value is 1. Exceeding this value indicates overproduction and failing to achieve it indicates the production of too few products in relation to the assumptions of the production plan. The company's qualitative target for rebated frame and panel interior doors is 0.94 (QR ratio). The summary in Figure 3 shows that only in one month, september, the target was clearly exceeded. In the other months, the QR index reached equal or lower values. The QBR taking into account the number of non-conforming but repairable products each month exceeded the acceptable value. Nevertheless, the achieved result should not be interpreted as a result that does not require adjustments, since the necessity to reprocess the products (repair) generates additional costs for the company. With the current number of nonconforming products, in order to meet the customers' requirements, the company is forced to produce more products than assumed in the prediction plans.

As part of the improvement activities of the production process, the sources of disturbances should be identified and their validity determined. The complaint data shows that the most frequent reasons for complaints were production discrepancies.

Recognition of the most significant inconsistencies from the point of view of the number of their occurrence and their effects was carried out using a Pareto-Lorenz diagram. Figure 4 shows the developed diagram for the problem of decreasing the quality level of rebated internal frame and panel doors.

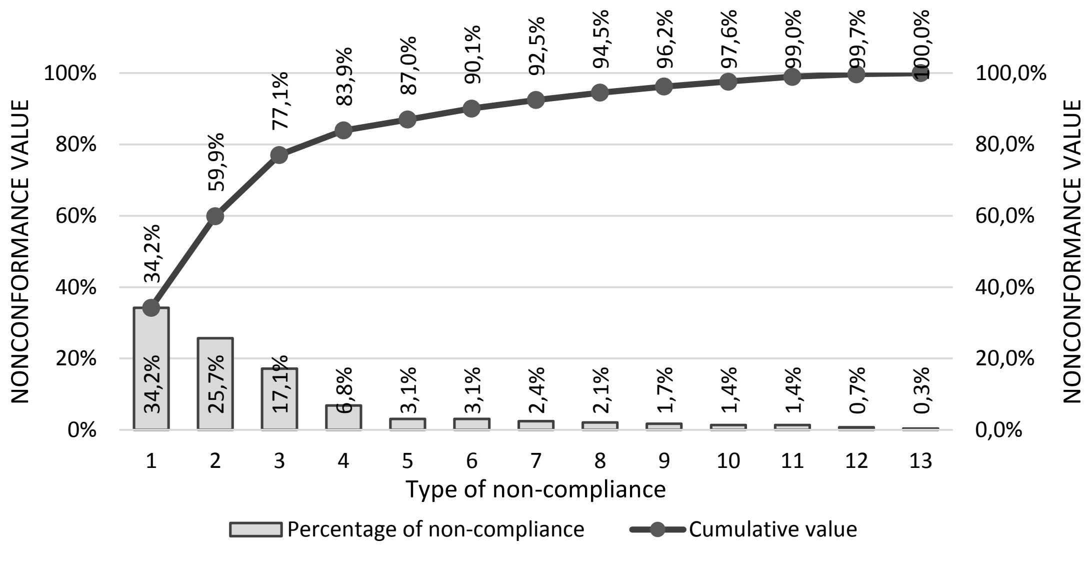

Figure 4. Pareto Lorenz plot for interior door incompatibility. Source: Own elaboration based on: Agmar Door materials. Unpublished materials. Chwałowice, 2019.

The incompatibilities included in the diagram of the non-conformities present in the test products are determined in turn: 1 – the uneven surface of the rim under the adhesive; 2 – inadequate geometry of the rim under the adhesive; 3 – inadequate installation of hinges; 4 – incorrectly mounted seal; 5 – inappropriate dimensions of the rim under the adhesive; 6 – scratches on the surface of the door leaf; 7 – no hinge overlays; 8 – inadequate geometry of the door leaf; 9 – damage/bruising of the door leaf; 10 – discolouration on the door wing;

11 – 2 – air blisters between layers of varnish; 12 – gasket defects on the door wing; 13 – adhesive leakage from under the seal.

The analysis of the batches of products has shown that the most serious nonconformity concerns the uneven surface of the rim under the rebate (34.2%). Critical discrepancies also included the presence of inadequate rim geometry under the rebate (25.7%) and incorrectly installed hinges (17.1%). Critical nonconformities, in the analyzed period, contributed to 77% of all nonconforming products. Immediate remedial action should be taken in relation to identified non-conformities and the process should be monitored.

The next step in the analysis of the decline in the quality of interior doors involved identifying the potential causes of the most significant nonconformance using an Ishikawa diagram. Figure 5 covers the key areas (material, machine) within which the most likely causes of a significant number of products with an uneven flange surface under the rebate have been identified.

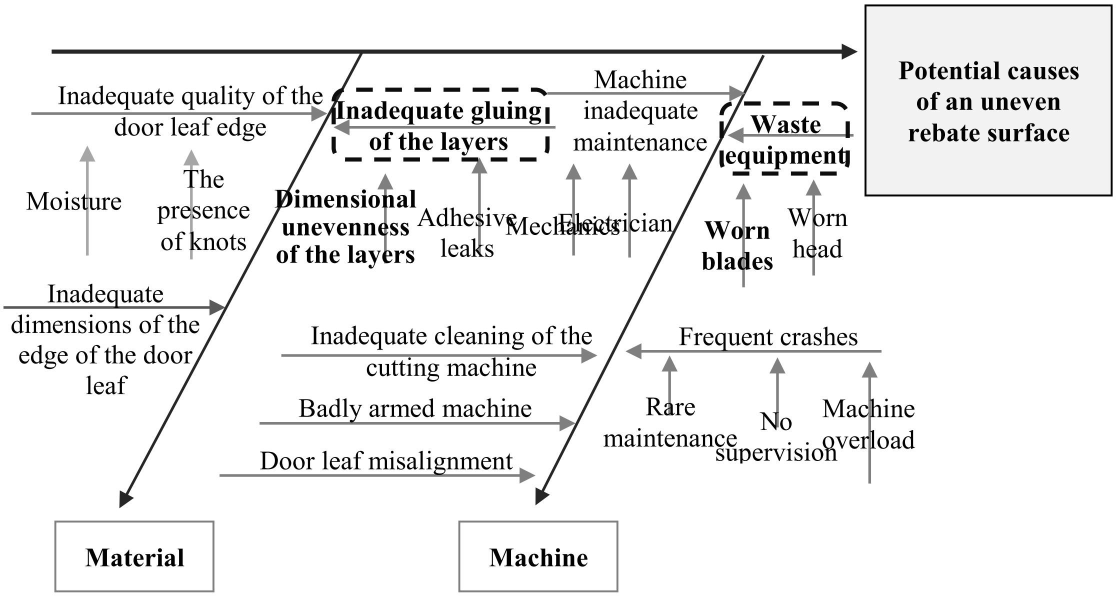

Figure 5. Cause-effect diagram for the most serious internal door non-conformities

Among the factors influencing the occurrence of nonconformities in the finished product, the use of worn-out equipment (worn-out blades) was singled out in the "machine" area. The improper condition of the blades in the machine used to make the flute for the rebate most likely contributed to the cutter not being made following the dimensional and surface roughness requirements. The second potential cause of this situation was inadequate glueing of the door leaf layers, which contributed to the unevenness in the edge area. In combination, these variables contributed to a significant number of products with uneven rim surfaces.

As a further analysis, the 5Why method was performed? for the problem of using used fittings in the saw and improper glueing of the door leaf layers. The result of the 5Why method? is shown in Figure 6, from which it was concluded that the root cause of both the use of worn hardware in the saw and the inadequate glueing of the door leaf layers was the lack of supervision, control and proper training of the worker. Inadequate employee management resulting in a lack of instructional training at the door leaf flange realization workstation contributed to a significant decrease in the quality of the production process.

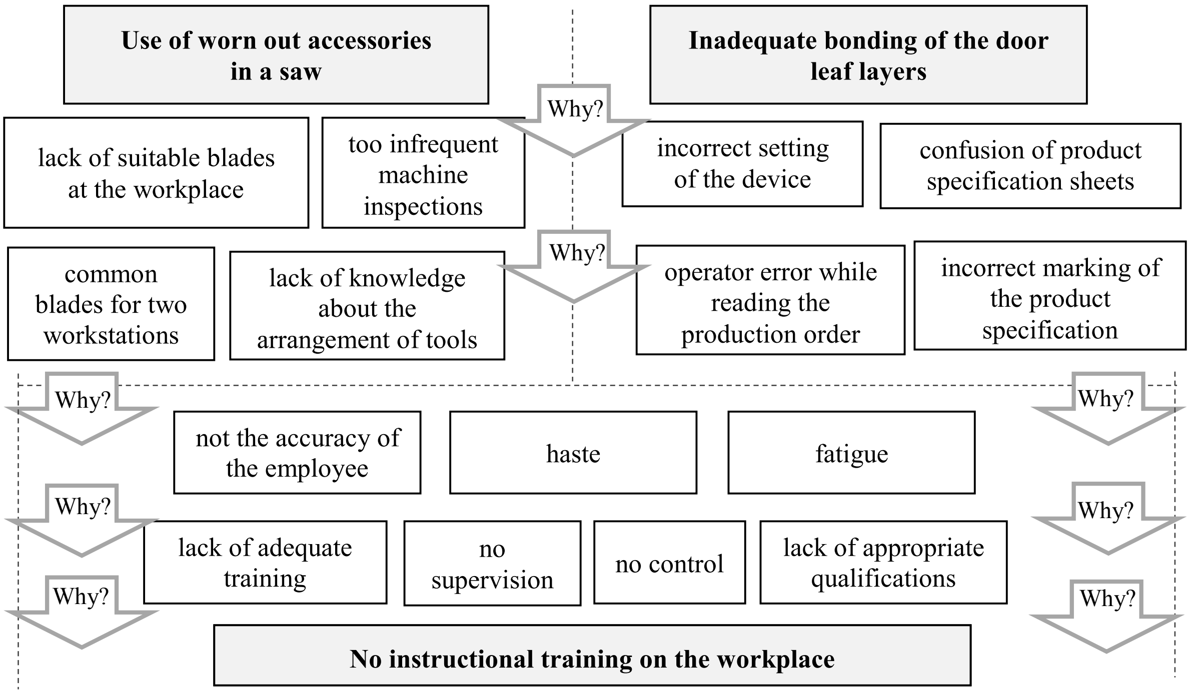

Figure 6. 5WHY method for the problem of using used accessories in a saw and inadequate bonding of the door leaf layers

As part of the improvement activities, a training plan should be developed for all production positions that are located within the production line of rebated internal frame and panel doors. In addition, develop and ensure the availability of job instructions at all workstations.

6. Conclusions

Properly selected indicators are the key element in the proper use of controlling in the organization. The indicators used in the production process require their incorporation into the structure and management system of the company. On the other hand, correlation of the supervision system with mutually complementary quality tools allows to ensure an appropriate level of quality of the offered products.

The paper presents research relating to the batch of rebated internal doors with frame and panel elements. The analysis conducted focused on the decline in quality levels and adverse events.

Frequencies and types of causes of incidents were presented by means of a Pareto-Lorenz diagram, which enabled the hierarchy of causes of product nonconformities, thus indicating the priority on which to focus remedial actions. The most common nonconformity was the presence of an uneven rim surface under the rebate. The next stages of the analysis were concerned with identifying potential causes of the identified non-conformity. After developing the Ishikawa diagram, it was found that the potential causes related to the material and machine area were inadequate gluing of the door leaf layers and the use of worn equipment for the rim processing. As part of further analysis, the 5Wh method was performer? On the basis of which, it was concluded that the root cause of both the use of a worn accessory in the saw and inadequate gluing of the layers of the door leaf was the lack of supervision, control and proper training of the worker. Therefore, as a remedial measure, responsibilities should be evenly distributed among employees and supervision and job training should be provided and job instructions should be available at all workstations.

Monitoring and correcting the production process through the use of KPIs and quality management tools is a methodology that helps to improve, steer the organization and indicate the emergence of problems in the company, thus enabling a dynamic response and documentation of actions and effects. The methodology presented in the study is a universal method of analysis, which can be used in any manufacturing company focused on continuous improvement.

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