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REORGANIZATION OF THE ASSEMBLY STATION IN THE PRODUCTION PROCESS OF THE SLIDING FLOOR FOR RELOADING RAMPS IN THE CONTEXT OF IMPROVING THE QUALITY OF THE FINISHED PRODUCT

REORGANIZACJA STANOWISKA MONTAŻOWEGO W PROCESIE PRODUKCJI PODŁOGI PRZESUWNEJ DO RAMP PRZEŁADUNKOWYCH W KONTEKŚCIE POPRAWY JAKOŚCI GOTOWEGO PRODUKTU

Abstract

The paper presents the definitions of the term quality quoted in the literature on the subject. FMEA (*Failure Mode and Effects Analysis*) methodology was presented. A reloading ramp was characterized as the subject of the study. A cause-and-effect analysis of non-compliance in the finished product was performed using the Pareto-Lorenz diagram, Ishikawa diagram and brainstorming. The FMEA analysis of the assembly table indicated the elements of the workstation causing the most frequently occurring non-conformities. Based on the obtained results, corrective actions were proposed to reorganize the assembly station. The implemented activities made it possible to reduce the critical RPN coefficients for the elements of the assembly table and to shorten the time necessary to make one piece of the finished product.

Keywords: quality, production process, FMEA, assembly, Ishikawa diagram

Streszczenie

W artykule przedstawiono definicje pojęcia jakość przytaczane w literaturze przedmiotu. Zaprezentowano metodykę FMEA (*Failure Mode and Effects Analysis*). Scharakteryzowano rampę przeładunkową jako przedmiot badań. Dokonano analizy przyczynowo-skutkowej powstawania niezgodności w wyrobie gotowym z wykorzystaniem diagramu Pareto-Lorenza oraz diagramu Ishikawy i burzy mózgów. Dzięki przeprowadzonej analizie FMEA stołu montażowego wskazano elementy stanowiska powodujące najczęściej powstające niezgodności. Na podstawie uzyskanych wyników zaproponowano działania korygujące, mające na celu reorganizacje stanowiska montażu. Wdrożone działania naprawcze umożliwiły obniżenie krytycznych współczynników RPN w elementach stołu montażowego oraz skrócenie czasu niezbędnego do wykonania jednej sztuki wyrobu gotowego na stanowisku montażu.

Słowa kluczowe: jakość, proces produkcyjny, FMEA, montaż, diagram Ishikawy

1. Introduction

The activity of each economic entity, regardless of the surrounding reality, is inextricably linked with the need to bear the costs of good or bad quality, resulting from the implementation of the object of activity. To survive in highly competitive markets, companies must constantly improve the quality of their products or services, with a flexible approach to changing needs and shortening order fulfillment cycles.

Quality has been around mankind since ancient times. The first references can be found in the time of the Hammurabi Codex. In the literature on the subject, there are many definitions of the term quality [3, 5, 6, 16, 17, 20, 24, 27, 30, 34]. As emphasized by Schindler,

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Puls-Elvidge, Welzant and Crawford, defining the concept of quality is difficult because [37]:

- quality is an elusive term with many different interpretations depending on stakeholder views,
- quality is a multi-dimensional concept.

Taking into account the multidimensionality, Garvin distinguished five dimensions in which quality can be perceived. Among them there are [7]:

- absolute quality understood as the perfection of the product [36],
- product-related quality [25],
- quality relating to manufacturing [9],
- quality in relation to user requirements [4] ,
- quality in relation to value [1].

The same author proposed that the definitions of the concept of quality should be divided into seven categories. He distinguished the following categories of definitions: general, related to production, product, user, value creation, multi-dimensional and strategic [7].

According to the above-mentioned authors, when analyzing the definitions of the concept of quality, taking into account the level of product quality, three groups of definitions can be distinguished:

- definitions of quality in terms of utility, taking into account three approaches: economic, technical and identification,
- quality definitions in terms of cost, i.e. taking into account the cost of the manufactured product,
- definitions of quality in terms of meeting customer needs.

The authors recognize that quality is a common phenomenon, but it is difficult to clearly define the concept of quality. The problem of quality is complex. It can be analyzed not only technically or economically, but also socially, philosophically or psychologically.

Manufacturing companies operating in the present conditions are forced to constantly improve their production processes and ensure the quality level of products in line with customer expectations. Many methods and quality management tools are used to carry out the cause-and-effect analysis, including: Ishikawa diagram (more on Ishikawa diagram see [13, 14, 18]), 8D method (more on 8D method see [12, 22, 23]) or FMEA analysis.

In the literature, there are descriptions about the issues which can be found on the assembly station [15, 19, 21, 28, 32].

The aim of this work is to reorganize the assembly station in the production process in terms of improving the quality of the finished product and reducing assembly time. As an example, the production of a sliding floor for docking stations was selected. The selection of the assembly station in the discussed production process was dictated by the analysis of non-compliance of finished products and the determination of the reasons for their formation. The evaluation of the proposed reorganization solutions was made on the basis of the FMEA method.

2. FMEA methodology

FMEA (Failure Mode and Effects Analysis) analyzes the cause-and-effect relationships of potential defects, taking into account the risk factor, and allows for earlier implementation of corrective actions to counteract failures, errors and their effects [10]. This method was initially used in the United States in the 1960s. The analysis was developed and used for the first time by NASA in space flight projects. Despite its success, this method was not used by other industries until the 1970s. In the early 1980s, US automotive companies formally introduced FMEA analysis to their product development processes [2, 26].

In the literature on the subject, two types of FMEA analyzes are most often distinguished: product analysis (D-FMEA) and process analysis (P-FMEA) [31, 33]. Process FMEA is used in processes that are difficult to control, in the planning phase of technological processes and service processes, in order to improve processes that do not provide the required performance [39].

The procedure of designing the FMEA analysis has been presented, among others, in the studies [26, 33, 35]. It consists of the following steps:

- creation of the FMEA team,
- description of the product, process that will be analyzed,
- creating a block diagram showing the main components (product FMEA) or process steps (process FMEA),
- creating a list of potential failures, their causes and impact on the product or process,
- assigning coefficients (Severity, Occurrence, Detection) for each non-compliance,
- RPN (Risk Priority Number) calculation according to the formula (RPN = Severity X Occurrence X Detection),
- development of a recovery plan,
- taking corrective actions,
- recalculation of RPN after implementation of corrective actions,
- comparison of RPN before and after implementation of corrective actions and reassessment of potential non-conformities.

FMEA analysis is used for [38]:

- systematic identification of possible product / process non-conformities,
- testing the probability of errors in the manufacturing or assembly process,
- elimination of non-compliance or minimization of the related risk,
- interpretation of factors that may affect the stability of the production process,
- searching for solutions to existing problems,
- indication of areas requiring increased supervision,
- audit planning.

3. Characteristics of a reloading ramp

Reloading ramps enable a direct connection of the delivery vehicle with the warehouse surface, which enables a forklift to enter the vehicle's load box. The loading ramp is equipped with a system that enables automatic adjustment of the ramp level to the vehicle floor. By using this tool, loading and unloading of a given product is performed only on a horizontal plane.

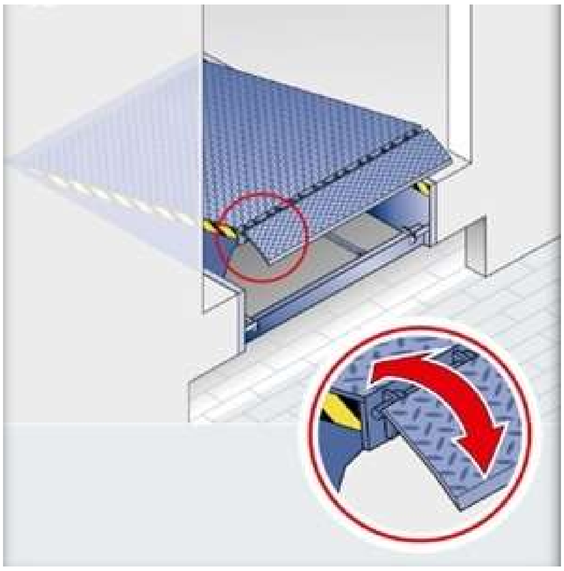

Fig. 1. Reloading ramp with a folding floor

Two types of ramps are manufactured in the examined enterprise. The principle of their operation and construction differ from each other only in the method of mounting the extendable platform (flap), which is a link between the ramp platform and the car loading surface. Both types of ramps consist of three basic elements: platform, tear plate and ribs stiffening the structure. The loading ramps are also equipped with frames, platforms, wheel guides and buffers (bumpers). The structure of the ramp with a sliding floor consists of interlocking beams of the platform, an extendable flap and side guide profiles (Fig. 1, Fig. 2). All loading ramps are manufactured in accordance with the provisions of the PN EN 1398 standard, and their size is appropriately adapted to the assumed load capacity.

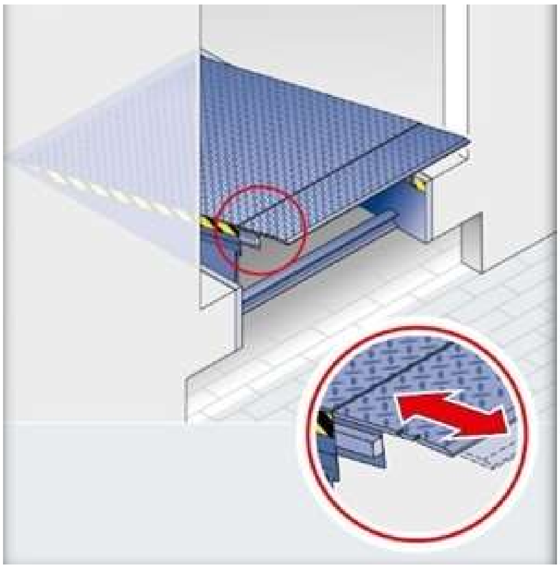

Fig. 2. Reloading ramp with a sliding floor

The time necessary to make one piece of the finished product at the assembly station is 45 minutes.

4. Cause-and-effect analysis of non-compliance in the finished product

The quantitative analysis was carried out in relation to products manufactured in one quarter. In the analyzed period 1250 units of a retractable platform for the loading ramp were manufactured. Based on internal complaints, 126 non-conformities were identified. Seven types of product non-compliance were noted. They included:

- D1 - incorrectly welded ribs,
- D2 - incorrectly welded beam,
- D3 - incorrectly positioned ribs,
- D4 - beam angle not maintained,
- D5 - folded ribs,
- D6 - scratches and surface crushing,
- D7 - unpainted surface.

Table 1 presents the defects in descending order with their percentage share calculated and cumulative values. This allowed the identification of a small number of defects that cause the most severe consequences. The most important problems in quality of finished products are:

- incorrectly welded ribs, which cause almost 35% of all defects,
- incorrectly welded beam, which cause almost 20% of all defects,

- incorrectly positioned ribs, which cause almost 13% of all defects,
- beam angle not maintained, which cause about 9,5% of all defects,
- folded ribs, which cause more than 8,5% of all defects,
- scratches and surface crushing, which cause almost 8% of all defects,
- unpainted surface, which cause more than 6% of all defects.

Based on the identified and sorted inconsistencies in Table 1, the Pareto-Lorenz diagram was prepared (Fig. 3). Two defects (D1 - incorrectly welded ribs, D2 - incorrectly welded beam) cause more than 50% of all defects. Four defects (D1 - incorrectly welded ribs, D2 - incorrectly welded beam, D3 - incorrectly positioned ribs, D4 - beam angle not maintained) result in more than 75% of all defects.

Table 1. Defects in the tested product

No defect	**Type of defect**	***Frequency* for 1250 pcs.**	***Frequency* [%]**	***Cumulative frequency***	***Cumulative frequency* [%]**
D1.	Incorrectly welded ribs	44	34,92	44	34,92
D2.	Incorrectly welded beam	25	19,84	69	54,76
D3.	Incorrectly positioned ribs	16	12,70	85	67,46
D4.	Beam angle not maintained	12	9,52	97	75,98
D5.	Folded ribs	11	8,73	108	85,71
D6.	Scratches and surface crushing	10	7,94	118	93,65
D7.	Unpainted surface	8	6,35	126	100,00

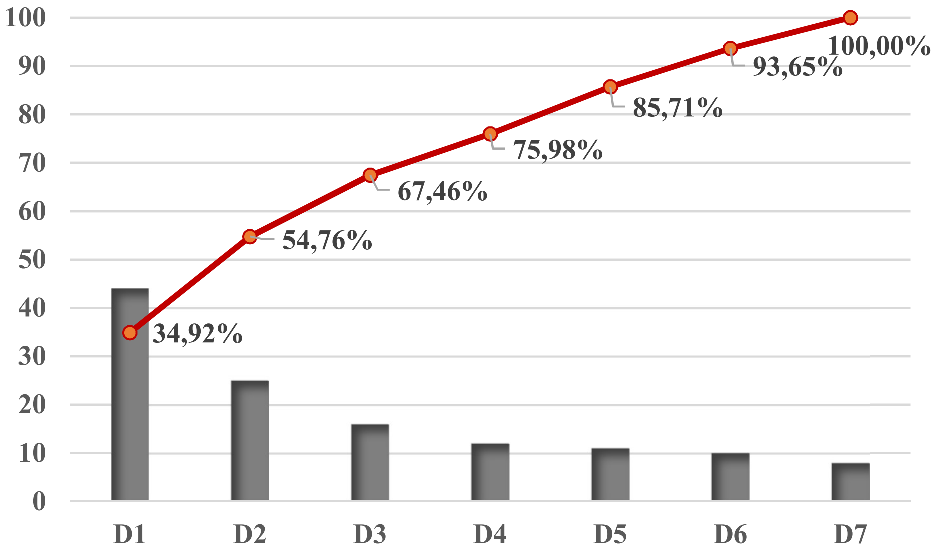

Fig. 3. Pareto-Lorenz diagram

For three inconsistencies, constituting nearly 70% of all inconsistencies, an analysis of the causes of inconsistencies was performed using the Ishikawa diagram. The main analyzed areas are described, among others, in [11]. Fig. 4 shows the Ishikawa diagram indicating the causes of the most common defect "incorrectly welded ribs". Determining the causes of non-compliance was possible thanks to brainstorming and observations of the assembly station employees. The cause-and-effect analysis has shown that the main cause of the incorrectly welded ribs lies in the construction of the assembly table.

While welding the ribs, workers have trouble keeping the ribs in the correct position, which results in incorrect welding. In the case of two consecutive irregularities, i.e. "incorrectly welded beam" and "incorrectly positioned ribs", the construction of the assembly table was also indicated as the main cause of the non-compliance.

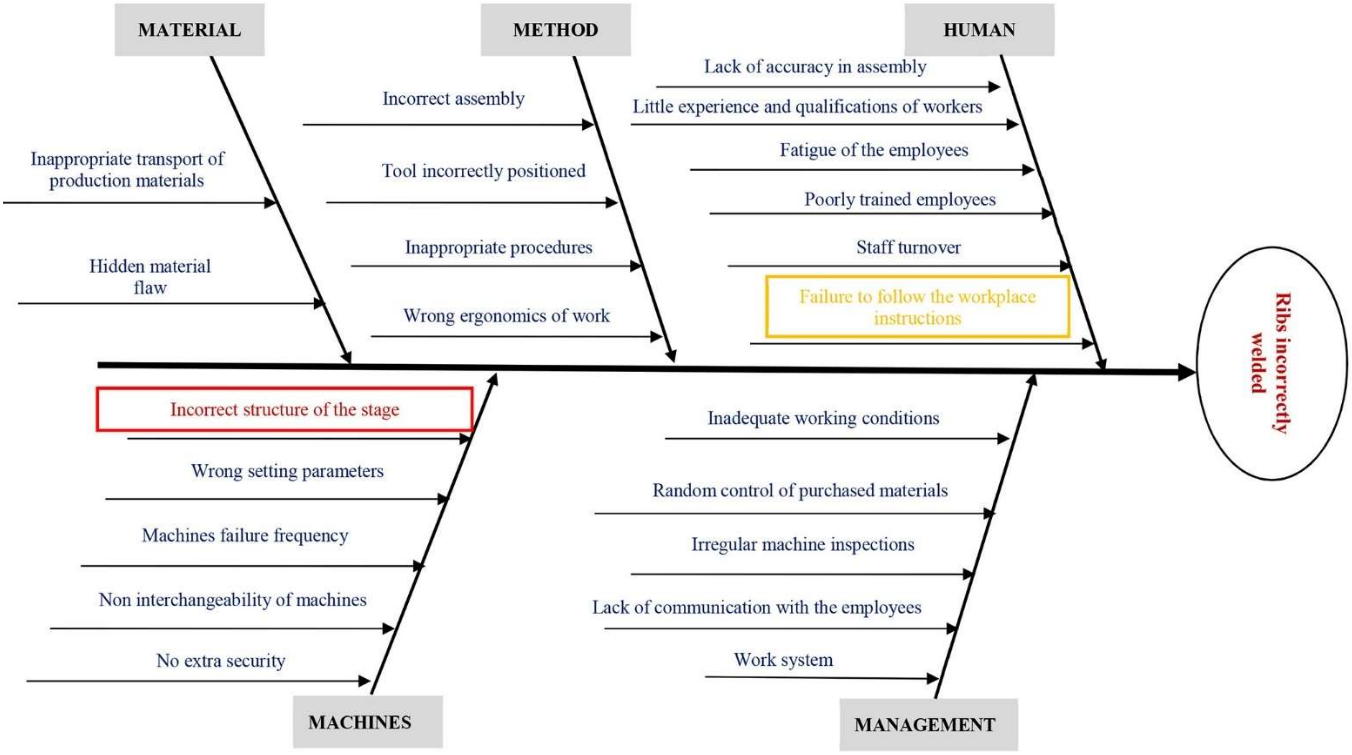

Fig. 4. Ishikawa diagram showing the causes of the "incorrectly welded ribs" defects

5. Reorganization of the assembly station - FMEA analysis

The most important incompatibilities of the finished product include: improperly welded ribs, improperly welded beam and improperly positioned ribs. The incorrect structure of the assembly table was indicated as the main cause of the defects.

The assembly table consists of the following elements (Fig. 5):

- rear strip,
- a pressure beam, which includes a lug fixing the position of the ribs, a movable beam and a ruler,
- hydraulic system,
- control system,
- table top for assembly, consisting of the rear beam guide, table legs and a roller for ejecting ready-made elements.

The rear strip is responsible for pressing the beam and setting the beam position. The task of the clamping beam is to maintain the rib angle and to press the rib against the platform (lug fixing the position of the ribs), and also to measure the distance of the ribs (ruler). The tasks of the hydraulic system include pressing the main beam, and the control system monitoring the hydraulic cylinders. The table top for assembly is a place for storing and welding the platform.

Based on conversations with the employees of the assembly station and own observations, a list of the elements of the assembly table responsible for resulting in the causes and effects of non-compliance in the finished product was created. In the next step, the RPN, i.e. Risk Priority Number, was calculated (Table 2).

The conducted FMEA analysis of the assembly table showed five most important defects (the RPN coefficient exceeds the value of 100, which is considered a critical value in the examined company), which affect the incorrect course of the assembly process. The irregularities concerned such elements as: the rear strip, the paw fixing the position of the ribs and the top of the stage. Considering the number of incompatibilities in the finished product, it should be noted that:

- the cause of an incorrectly welded rib is the lack of pressing force on the internal ribs, which

affects the fact that the ribs do not have a right angle during the assembly process,
- the cause of an incorrectly welded beam is improper structure of the beam, in which there are bolts, which while pressing the beam move the beam away from the platform,
- the cause of improperly positioned ribs is the curved surface of the assembly table, which causes the platform to bend.

Based on the obtained results, a repair plan was developed taking into account the structural changes of the assembly station, corrective actions were implemented, and then the RPN coefficient was recalculated (Table 3). The repair plan for the construction of the assembly table included the following actions:

- the use of a bar clamping the beam with a chain,
- the use of an electromagnet,
- changing the structure of the rib paw,
- placing a pneumatic actuator on each foot,
- use of thicker material for the table top - introduction of a strengthening frame.

The time necessary to make one piece of the finished product at the assembly station after implementing corrective actions was 30 minutes. Table 4 shows the results of the FMEA analysis of the stage before and after the implementation of corrective actions.

Fig. 5. Assembly table

Table 2. FMEA analysis for the assembly table

Assembly table element	Cause of defect	Consequences of a defect	RPN			
			R	P	N	RPN
Rear strip	Incorrect construction of the rear strip	Beam incorrectly welded	7	3	6	**126**
	Moving beam	Beam angle not maintained	6	3	6	**108**
Paw fixing the position of the ribs	Wrong paw construction	Wrinkled rib	8	2	7	**112**
	No downforce on the inner ribs	Rib badly welded	7	3	7	**147**
Ruler	Unreadable reading from the ruler	Ribs incorrectly positioned	3	2	8	48
Hydraulic system	Broken serpent	No oil pressure	3	2	4	24
	Damaged actuator	Actuator not working	3	3	5	45
Control system	Damage to electrical wires	No actuator reaction	2	6	8	96
Table top for assembly	The curve of the table surface - dents and unevenness	Ribs incorrectly positioned	6	3	7	**126**

Table 3. FMEA analysis for the assembly table after the implementation of corrective actions

Assembly table element	**Cause of defect**	**Efforts to improve**	**RPN**			
			R	**P**	**N**	**RPN**
Rear strip	Incorrect construction of the strip	The use of a bar clamping the beam with a chain	5	3	6	**90**
	Moving beam	The use of an electromagnet	1	3	6	**18**
Paw fixing the position of the ribs	Wrong paw construction	Change in the structure of the rib paw	2	2	7	**28**
	No downforce on the inner ribs	Pneumatic actuator is placed on each foot	3	3	7	**63**
Assembly table top	The curve of the table surface - dents and unevenness	The use of a thicker table top and the introduction of a reinforcing frame	5	2	7	**70**

Table 4. Assembly table FMEA analysis results before and after the implementation of corrective actions

Assembly table element	**Task**	**RPN before modernizing the assembly table**				**RPN after modernization of the assembly table**			
		R	**P**	**N**	**RPN**	**R**	**P**	**N**	**RPN**
Rear strip	Pressing down the beam	7	3	6	**126**	5	3	6	**90**
	Setting the position of the beam	6	3	6	**108**	1	3	6	**18**
Paw fixing the position of the ribs	Maintaining the rib angle	8	2	7	**112**	2	2	7	**28**
	Pressing the rib to the platform	7	3	7	**147**	3	3	7	**63**
Assembly table top	Assembly and welding of the platform	6	3	7	**126**	5	2	7	**70**

6. Summary

The aim of the work was to reorganize the assembly station in the production process in terms of improving the quality of the finished product and reducing the assembly time. Based on the conducted analyzes, it can be concluded that:

- the Pareto-Lorenz analysis showed that the incidence of "incorrectly welded ribs" was 34.92%, "improperly welded beam" - 19.84%, and "incorrectly positioned ribs" - 12.70%,
- analysis of the Ishikawa diagram and brainstorming indicated that the most common causes of non-compliance are: incorrect construction of the assembly table, non-compliance with workplace instructions, improper ergonomics of work and lack of communication with employees,
- the FMEA analysis of the assembly table showed that the elements of the station causing the most frequently occurring non-conformities are: the back strip, the clamp fixing the position of the ribs and the top of the assembly table,
- on the basis of the FMEA analysis of the assembly table, in relation to the critical causes of non-compliance, the following corrective actions were proposed: the use of a bar clamping the beam with a chain, the use of an electromagnet, changing the structure of the rib paw, placing a pneumatic actuator on each paw, as well as using a thicker table top and the introduction of a strengthening frame,
- corrective actions reduced the critical RPN coefficients in the elements of the assembly table and shortened the time necessary to make one piece of the finished product at the assembly station from 45 minutes to 30 minutes.

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