[1.] Miriama PINOSOVA, [2.] Miriam ANDREJIOVA

ANALYSIS OF THE ERROR RATE IN PCB PRODUCTION USING QUALITY MANAGEMENT TOOL

[1.] Technical University of Kosice, Faculty of Mechanical Engineering, Department of Business Management and Environmental Engineering, Kosice, SLOVAKIA
[2.] Technical University of Kosice, Faculty of Mechanical Engineering, Department of Applied Mathematics and Informatics, Kosice, SLOVAKIA

Abstract: Quality control and improvement have become an important business strategy for many production organizations. Quality is a competitive advantage and therefore in every production process, it is necessary to implement quality management methods constantly. The aim of this paper is the analyse the most common errors and their causes in the production process of printed circuit boards (PCB) the production process using the selected quality management tools. Basic quality management tools were used for analysis and evaluation, namely FMEA, Pareto chart and Ishikawa diagram. The individual procedures for analyzing a given production process identified errors for which it was necessary to design and take measures to reduce or eliminate them entirely. As part of the analysis, we addressed two of the most numerous errors Err1 (missing part) and Err2 (missing Pin). In both cases, it was confirmed to us that the human factor had a significant influence on the number of these errors.
Keywords: FMEA, Pareto Analysis, Ishikawa diagram, Quality Management Tools

1. INTRODUCTION

Quality has become one of the most important factors in consumer choice between competing products and services (Montgomery, D.C., 2008; Hashemzahi, P., et al, 2020). Ensuring it is a controlled process that includes people, a system of production or service-provision, and supporting tools and methods, so it can be measured using quality management standards from the EN ISO 9000:2000 series Quality Management Systems – Fundamentals and Vocabulary (definitions) (EN ISO 9000, EN ISO 9001 and EN ISO 9004). Under ISO 9000, quality is actually the sum of all product's characteristics and features related to the ability to meet specific requirements that are usually determined by customers and their demand for quality in a product or service is constantly increasing. According to (Kumar Sharma, R., Gopal Sharma, R., 2014), global competition forces small and medium-sized enterprises to increase their competitiveness by increasing the performance of their production. They must pay attention to the reliability of their production processes and also their commitment to quality management procedures. Effective improvement of quality leads to increased productivity, reduction of production costs and thereby strengthens the position of the organization in the market. Quality is one of the tools of competitiveness and it is an integral part of the overall business strategy of organizations.

Quality management is a targeted activity of the organization through Quality Management Systems (QMS), which are focused on meeting quality requirements, proposing appropriate methods and tools to meet quality objectives, regularly checking them and taking measures for continuous improvement. From the consumer's point of view, we can define quality as the extent of the product's ability to perform the functions for which it was intended (Berk, J., Berk, S., 2000). From the manufacturer's point of view, quality is associated with the technical level of the product in question under the prescribed conditions. The authors of the article use an integrated approach to the perception of the quality of the item from the customer's point of view and directing the relevant information into the product development process (Falk, J., et al, 2010).

Failure modes and effects analysis (FMEA) is a useful tool for analyzing the production process. FMEA was first proposed and applied in the Aerospace Industry in the 1960s for reliability and security analysis and has been widely utilized in the aerospace, manufacturing, healthcare, marine, construction, and engineering industries (Bradley, J.R., Guerrero, H.H., 2011; Carpitella, S., et al, 2018). According to (Stamatis, D.H., 2003), FMEA is a method used to define, identify and/or eliminate known and/or potential faults, problems, errors with the system, product, design, and/or services before they reach customers. It is used to prioritize three criteria: probability of failure, severity of failure and detection of failure (Liu, H.-C., 2016). Vulpes T.C., and Opran, C.G. in years 2021 they state that FMEA is one of the most efficient and effective methods for preventing faults and other discrepancies. Its importance lies in assessing the possible failure of component functions during the manufacturing process, their causes and effects in order to identify preventive measures that may result in higher reliability of the product.

Quality management methods also include statistical methods that use probability theory and processes from mathematical statistics to manage quality. According to (Vardeman, S.B., Jobe, J.M., 2016;

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Montgomery, D.C., 2008), statistical methods play an essential role in controlling and improving the quality of the production process, services, etc. These Statistical Process Control (SPC) methods are used not only to measure and monitor process performance, but also to provide a basis for improving it. According to (Mitreva, E., et al, 2019), by using SPC methods and cost optimization methodology it is possible to achieve defined quality and better productivity with the lowest operating costs. The seven basic tools of SPC include histograms, check sheet, Pareto chart, cause-and-effect diagram (Ishikawa diagram), defect concentration diagram, scatter diagram and control chart (Montgomery, D.C., 2008). These tools are easy and simple to use and can be applied to any process. Filz M.-A. et al. used the FMEA method to improve scheduled maintenance. The FMEA method was also used to analyze the causes of deficiencies in the production of Covid-19 face masks using the 3D printing method (Rochman, D.D., et al, 2021). In article (Duarte, T.S., 2021), the authors apply the DMAIC (Define, Measure, Analyze, Improve, Control) method, together with quality tools such as brainstorming, Ishikawa diagram and Pareto chart, to analyze and reduce failure in some products' pneumatic brake system. Reliability, availability and sustainability in a bag sector is analyzed by (Tsarouhas, P., 2020). He uses statistical quality management methods (descriptive statistics, Pareto chart, histogram, and others) to analyze production line failures. The optimization of the production chain, from the early stages of the design of production systems to the start of production of lithium-ion cells, was examined by (Westermeier, M., et al, 2014). They also used the Pareto chart in the evaluation and analysis of the production chain.

The authors of (Amrani, M.A., et al, 2020) used basic quality management tools (Ishikawa diagram, Pareto chart and others) to identify the root causes of machine failures in production. In improving the injection moulding process, the authors of (Maged, A., et al, 2019) used quality management tools, namely statistical process control (SPC), Pareto chart, histogram, Ishikawa diagram, measurement system analysis, hypothesis test and checklist. The statistical methods of quality control (Ishikawa diagram and Pareto chart) were also used in identifying the main factors influencing the process of pyrolysis of petroleum sludge, and also the causes of failures for which elimination is of essential importance (Kolenchukov, O.A., et al, 2019). Li B., et al. use statistical process control and data-mining technology for evaluations and improvements to the semiconductor element production process. Parmenter, D., dealt with optimization in the production process by introducing monitoring systems that allow the collection of production data but also reporting various malfunctions or adverse effects.

2. MATERIAL AND METHODS

Production process

The company in which error analysis was carried out in the production process using quality management tools is a manufacturer of industrial electronics. It has been operating in Slovakia since 2000. The organization has an integrated management system and holds certificates that demonstrate compliance with the requirements of the ISO 9001:2015 (Quality management systems – Requirements), ISO 14001:2015 (Environmental management systems – Requirements with guidance for use) and ISO 27001:2013 (Information technology – Security techniques – Information security management systems – Requirements) standards. The basis of production is 6 assembly lines where the production of printed circuit boards (PCBs) takes place from their installation, testing and final assembly to the delivery of the finished product to the customer.

One of the production lines of this company analyzed in this paper is semi-automatic with manual production predominating. This is the finalization line on which PCB production is completed.

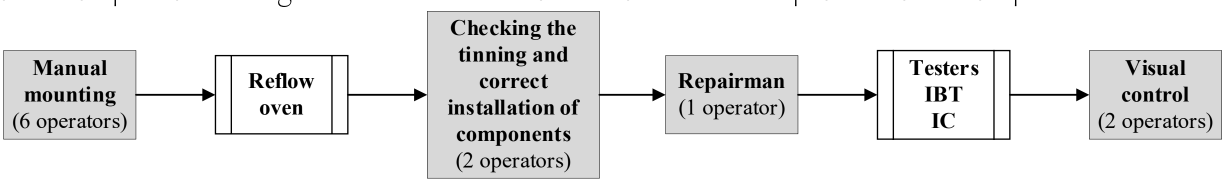

Figure 1. PCB production process

There are 11 operators working on the production line (Figure 1). They have workflows that describe individual work operations with the names and component labels for specific PCB models. Depending on the model currently being produced, operators choose a workflow and check the individual components (name, label, print). The first operator places an identification sticker on the PCB showing the model's name, date of manufacture and 2D identification code. The tagged PCB then moves to the next operator who places the corresponding components on the PCB and moves it further along the line. In this way, the

PCB board still goes through a manual process to the last operator, who checks the correct installation of all components and releases the board to the reflow oven.

The board goes further along the production line belt, passes the refrigeration equipment and proceeds to another operator for bare-board testing which removes possible short circuits and open joints on the PCB. Another checks the correct installation of components and moves the PCB to the testers.

The first tester in turn is IBT. This is a test technique for testing installed printed circuit boards, which requires contact with each IC connector. PIN testers are also involved in IBT, which inspects the connectors of the installed components. The second is FT, which checks the correct function and prescribed PCB specifications. The board tested in this way continues to the final visual inspection. The PCB is visually inspected first from the Hand side and then from the SMD side. The inspected board then goes into the box and is ready to pack.

If, during testing, one of the testers evaluates the PCB as defective, the IBT operator corrects the tester and inserts it for re-testing. If the error can't be removed, they tag the PCB with a sticker and take it to a specialized repair facility.

Methods

Three selected quality management tools (FMEA, Pareto chart and Ishikawa diagram) are used to analyze the error rate of a particular production process. FMEA is one of the basic tools applied within ISO 9000 standards. The aim of FMEA is to analyze potential errors in a particular system, over a selected period of the service life of the system, so that corrective measures can be taken to reduce the risk that the emergence of errors entails. According to (Bradley, J.R., Guerrero, H.H., 2011), an FMEA system can be achieved using a series of steps that include conceptual design, detailed design and development, test and evaluation.

Pareto analysis is one of the most effective quality management tools, which makes it possible to separate the root causes of a particular problem from the minor ones, thus showing the direction in which efforts to ensure quality assurance in the process need to be focused in order to remedy its shortcomings. Pareto analysis is based on the Pareto chart. The Pareto chart is named after the Italian economist Vilfredo Pareto (1848–1923), who considered that in certain economies a small proportion of the population held the majority of wealth (Parmenter, D., 2007). The Pareto chart was first used in quality management by Juran J.M. (1904–2008), who stated that this principle can also be applied to errors, with 80% of the problems being caused by 20% of the defects (Best, M., Neuhauser, D., 2006). A Pareto chart is a column chart of absolute, or absolute relative, occurrences of individual causes, in which are also plotted the points of the Lorentz curve representing the polygon of cumulative relative occurrences of each cause (in %). According to Montgomery D.C., the Pareto chart does not automatically identify the most important defects, but only the most frequent. Therefore, in addition to simple Pareto analysis, weighted Pareto analysis is often used, in which each type of error is assessed by the degree of severity of the error. Pareto analysis often uses the 80/20 or 75/25 rule, which means that it is recommended to include causes with a cumulative number from 0 to 80%, or from 0 to 75%) in a more detailed analysis of the causes.

Ishikawa K. (1915–1989) developed a simple tool to identify possible causes of a problem, known as a "cause and effect diagram" (or a fishbone diagram). Very often a version of the diagram with the main categories of causes is used: People, Material, Machines, Methods and Environment (Jones, E., 2019).

3. RESULTS AND DISCUSSION

The analysis and evaluation of the quality of the production process is divided into three parts:

- Analyzing the production process using the FMEA method,
- Evaluating the occurrence of errors using Pareto Analysis and Pareto Chart,
- Finding the main causes of the most common errors using the Ishikawa diagram,
- Proposing measures to eliminate the most significant errors.

FMEA of the process

The aim of the analysis was to analyze the production process and to determine the occurrence of errors at the different stages of production. The main tool in the development of FMEA was brainstorming.

As part of process evaluation, the function and requirements of the process, possible defects (faults) of the product, possible consequence of the occurrence of errors and the severity of the errors were monitored. The research included analysis of the probability of the error occurring and its possible cause.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

The result was the determination of a risk priority number (RPN), which is ex-pressed as the product of three indices (severity, frequency, detection), where each index can receive a score in a certain interval. In our case, the score is on a scale of 1 to 5 (Table 1). The resulting RPN value is between 1–25 points.

Table 1. Rating for frequency, severity and error detection

Rating	Occurrence	Severity	Detection
5	Very high	Very high	Very low
4	High	High	Low
3	Moderate	Moderate	Moderate
2	Low	Lower	High
1	Nearly impossible	None	Very high

FMEA pointed to some critical points in the production process. Measures to eliminate deficiencies were recommended for these production areas. The implementation of the measures has resulted in a significant reduction in the values of the RPN (Table 2). Based on the RPN index, a risk level was established (low rate: RPN from 1–10 points; mean rate: RPN is from 11–14 points; high risk level: RPN ≥15 points). The mean level of risk has been identified at production stages such as material preparation, glue application, capacitor, filter, connector mounting. For risks exceeding a specified value of 15 points, include 4 functions of the process (Table 2).

Table 2. FMEA (RPN index ≥15 points)

Function / RPN	Possible cause / effect	Measures / RPN
Installation of ceramic capacitor (RPN=20 points)	connectors do not pass through the PCB hole / may cause the part to be thrown out or lifted during subsequent handling	addition of control Pin tester to IBT (RPN=10 points)
Installation of AC Inlet (RPN=20 points)	incorrect installation of the component / malfunction of the device	installation of a camera to check Pins, retrain employees (RPN=10 points)
Installation of fuse (RPN=20 points)	unwetted area when installed / malfunctioning PCBs	addition of Pin tester (RPN=10 points)
Installation of coil (RPN=18 points)	failure to follow the workflow / change of polarity on the device	addition of polarity tester, retraining of employees (RPN=12 points)

Pareto analysis

In the analysis of errors in the production process, data from two time periods were used: 2021 (September, October) and 2022 (February, March), which were comparable in terms of production volume. Error analysis focused on the production line system for hand-installed components on the printed circuit board (PCB) – the final step of production. The errors observed, together with the degree of severity of the errors (weight of errors) obtained for the periods, are listed (Table 3).

The degree of severity (determined with the assistance of experts from practice) is expressed using a natural number between 1 and 10, with 10 being the most serious error.

Table 3. Description of errors by weight for Pareto analysis

Designation	Description	Degree of severity (weight)
Err1	missing component	7
Err2	missing Pin	10
Err3	lifted component	8
Err4	non-soldered area	9
Err5	short circuit	8
Err6	reversed polarity	9
Err7	shifted component	7
Err8	other errors	6

Figure 2 is a graph showing the occurrence of errors in the manual installation of components during the reference periods. A total of 1978 deficiencies were identified in the two reporting months of 2021 (September and October). The most significant number is in the case of error Err1 (missing part), which accounted for almost 35% of the total number of noted errors. In 2022 (February and March), 1447 component planting defects were identified, representing a reduction of almost 27%. Again, the most significant number was error Err1 (missing part), which accounted for approximately 32% of the total number of noted errors in a given period.

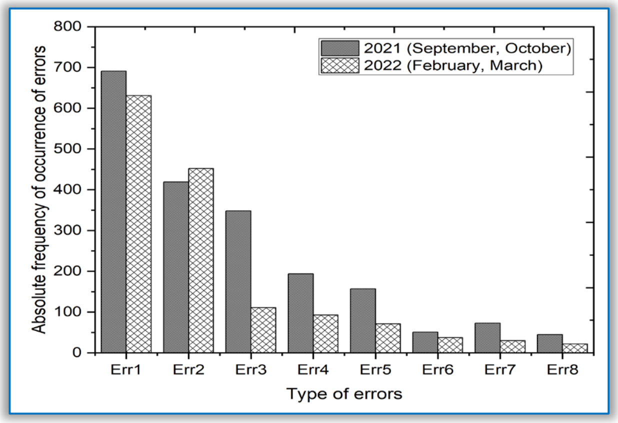

Figure 2. Occurrence during the reference periods

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

For evaluation using Pareto analysis, we chose the 75/25 criterion, under which it is recommended to monitor in more detail errors for which the cumulative relative number for F_i reaches a value equal to 75%. We took into account not only the absolute frequency of occurrence of individual n_i errors, but also their degree of severity w_i (weight). We obtained the weighted number of wn_i errors as a product of the absolute frequency of occurrence of the error and its degree of severity. Table 4 shows the weighted Pareto analysis for both periods under review, which also shows the cumulative absolute number N_i.

The results obtained show that the situation in terms of product quality has improved over a number of months. Absolute error rates (except for Err2) decreased significantly. In the case of Err3 error, the decrease is by up 68%. An analysis of the production process showed that Err3 error, were mainly due to the "cooler" component, which has multiple connectors, is harder to install, and can get raised in the oven. For this reason, it was proposed to adjust the setting of the oven by changing the shape of the weights used to load the cooler before it enters the oven. The situation also improved with the Err1 error (a decrease of almost 9% compared to the previous period). In the case of the Err2 error, the absolute number increased by almost 8% compared to the previous period. Therefore, for the Err2 error, it was been proposed to add an In-circuit Board Tester IBT (In circuit Board Tester) control Pin to check the length of the connectors. Adding this will extend the testing time, but will improve the quality of the supplied board.

Table 4. Weighted Pareto analysis

Time period	Error	n_i	w_i	w_{ni}	N_i	F_i
2021 (September, October)	Err1	691	7	4837	4837	0.312
	Err2	419	10	4190	9027	0.582
	Err3	348	8	2784	11811	0.762
	Err4	194	9	1256	13067	0.843
	Err5	157	8	1200	14267	0.920
	Err7	73	7	511	14778	0.953
	Err6	51	9	459	15237	0.983
	Err8	45	6	270	15507	1.000
2022 (February, March)	Err2	452	10	4520	4520	0.380
	Err1	631	7	4417	8937	0.751
	Err3	111	8	888	9825	0.825
	Err4	93	9	837	10662	0.896
	Err5	71	8	568	11230	0.943
	Err7	37	9	333	11563	0.971
	Err6	30	7	210	11773	0.989
	Err8	22	6	132	11905	1

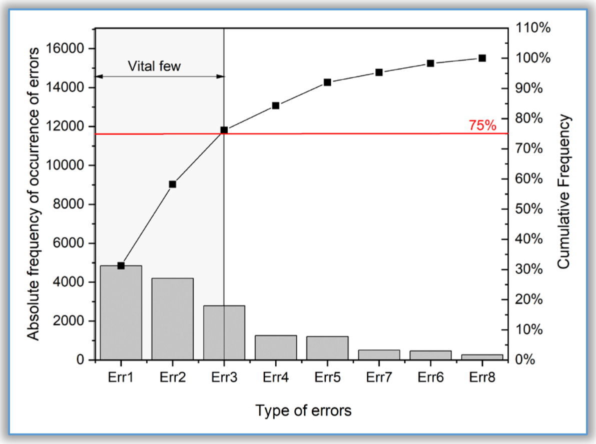

Figure 3. Pareto chart (2021 – September, October)

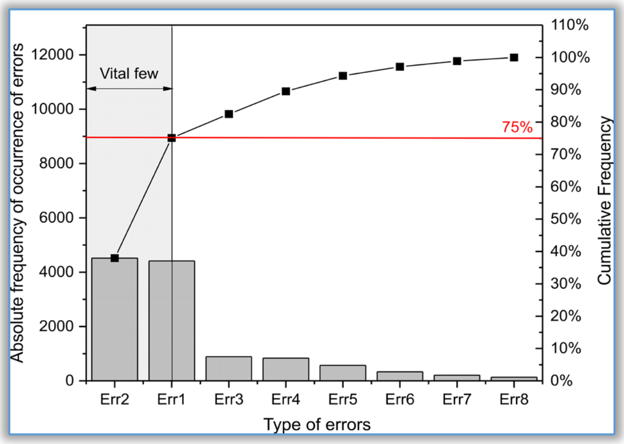

Figure 4. Pareto chart (2022 – February, March)

The Pareto chart shows that during the two months in 2021, three defects formed a vital group of causes of poor-quality products: Err1 (missing part), Err2 (missing Pin) and Err3 (raised part). In total, these three errors accounted for up to 76% of all detected errors in the final stage of the PCB production process (Figure 3).

In 2022, the order of errors changed slightly. The vital group of causes consists of only two errors: Err2 (missing Pin) and Err1 (missing part), which represent up to 75% of all errors in the production process during the given period (Figure 4).

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Ishikawa diagram

The Ishikawa diagram or fish bone diagram is an appropriate tool for solving problems arising from the results of Pareto analysis. Under the chosen criterion (75/15), it is recommended to address a vital group of causes of poor-quality products in the next step of the evaluation of the quality of the production process. In the case of the monitored production process, these are errors Err2 (missing Pin) and Err1 (missing part).

In each main category, (people, material, machines, methods, environment), several causes were involved in the significant number of Err1 and Err2 errors, which are illustrated through the Ishikawa diagram (Figure 5, Figure 6). The basic sub-products for which measures have been proposed to eliminate Err1 or Err2 errors number are indicated in red.

From the main category "Machines" Err1 error significant causes are mainly due to belt and feeder faults. If the belt malfunctions, the part may be thrown from the printed circuit board before it is soldered. In the event of a failure of the feeder, the board is pushed out with the pressure piston "pusher" and if set up wrongly this can break off the part mounted from the SMD (Surface Mount Device) side. The "Methods" category has an impact on the workflow that can be poorly or complicatedly written and misunderstood by the line operator. The cause most involved in the number of Err1 error is the "People" category, where compliance with working procedures, necessary concentration and length of training are crucial.

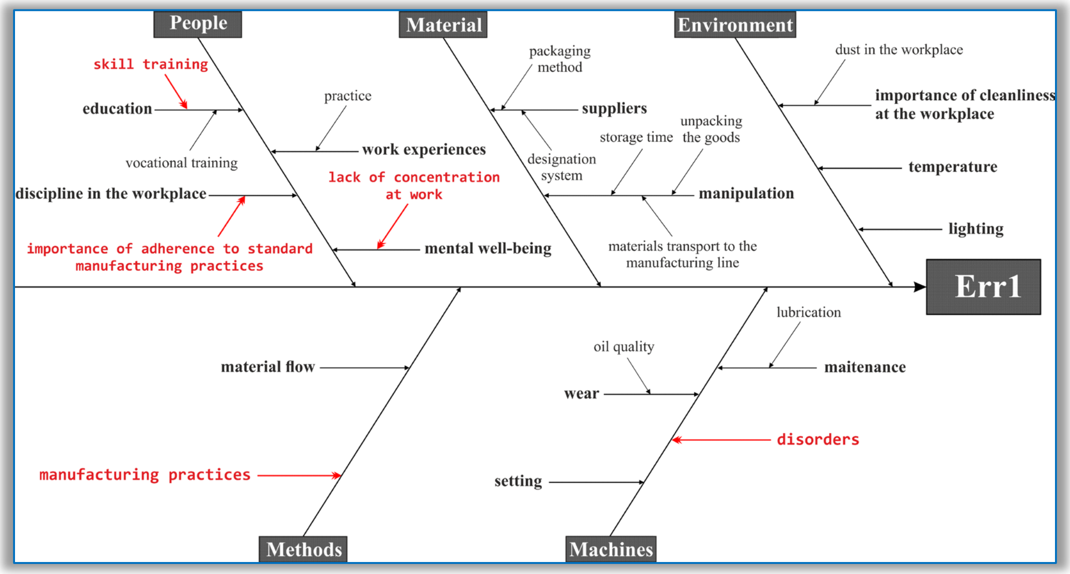

Figure 5. Ishikawa diagram for Err1 (missing part)

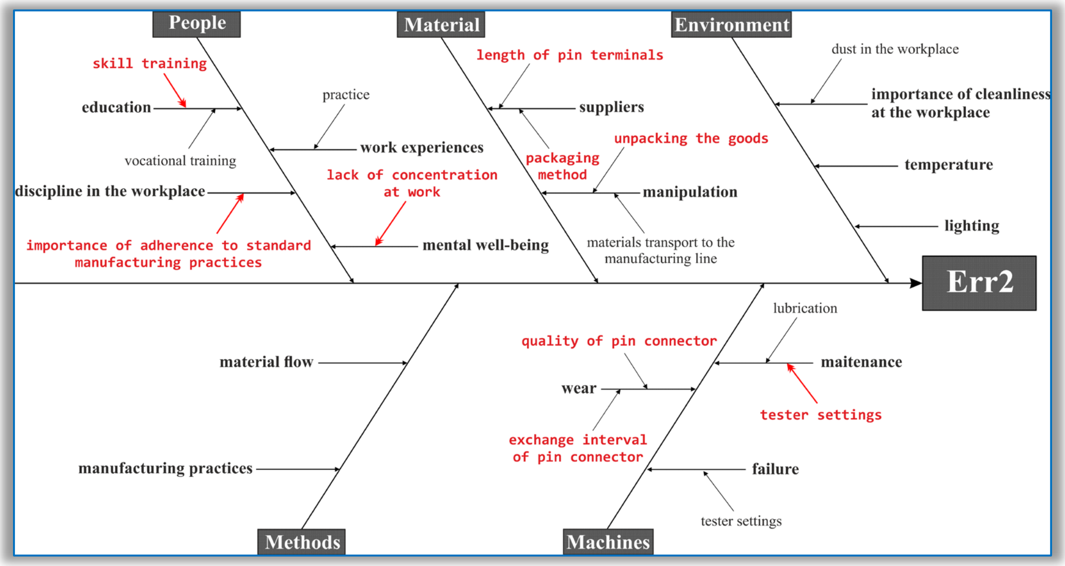

Figure 6. Ishikawa diagram for Err2 (missing Pin)

The frequency of the Err2 error was mainly affected by the method of packaging and handling during unpacking and transport. Inappropriate packing of individual components, especially capacitors as the

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

connectors on them are made of soft material, can easily lead to their being bent, resulting in more difficult mounting on PCBs. In case of incorrect unpacking, the connectors are bent, which also has an adverse effect on the quality of the PCB installation. In the case of the "Machines" category, the setting and maintenance of the tester, and also wear and tear of the control Pin and the interval of its replacement and failure, are a significant cause. From the category "People" it is mainly work experience, working discipline, focus on the work performed and adherence to the prescribed workflow.

4. CONCLUSIONS

For each production organization, quality is what the customer asks for and that's what every company is trying to provide. With quality tools, smooth, fast and trouble-free production can be achieved by identifying a production problem area in a timely manner. Quality tools such as FMEA, Pareto Analysis and Ishikawa diagram may be used for this activity.

This paper examines selected quality management tools and their use in the analysis of the error rate of the production of printed circuit boards. The individual procedures for analyzing a given production process identified errors for which it was necessary to design and take measures to reduce or eliminate them entirely.

Using the Risk Priority Index, FMEA has clearly highlighted the critical points in the production process for which the necessary measures have been proposed to prevent these errors. Pareto analysis identified the causes of key errors in the working environment, namely the Err1 and Err2 errors. An Ishikawa diagram is a very powerful tool for analyzing the causes of errors in the production process. For better diagnosis of the problem, for each major category of causes, subcategories were determined, supplemented by other minor causes with their share of the observed error. As part of the analysis, we addressed two of the most numerous errors Err1 and Err2. In both cases, it was confirmed to us that the human factor had a significant influence on the number of these errors. Therefore, human resources need to be given at least as much attention as technical equipment, finance and other production capacities. The proposed measures for the three most important main categories (People, Machines, Methods) are summarized in Table 5.

Table 5. Summary of proposed measures

Category	Measure
People	Rewrite workflows into a more comprehensible and clearer form. Retrain operators and educate them about the internal rules of the organization. Inform operators about the number of errors caused by them and motivate them to work better. Set up training rooms for newly recruited operators where they will undergo two weeks of skills training before starting work
Material	Change the way in which the components are unpacked and supply capacitors to the operator on the line in their original packaging. Specify the length of the connectors. Add a pin control camera on the safety component
Machines	Shorten the interval for replacing contact Pins in the tester. Consider changing the Pin supplier for better quality. Always check the height of the control Pin setting at the beginning of the shift, depending on the product type produced.

Currently, a lot of attention is paid to the quality of any product. In addition to increasing requirements for increased and accelerated production, this is due to the growth of customer requirements for the quality of the final products. Deficiencies and defects will always appear in the production process. Defining significant errors and their causes enables your organization to focus on reducing or eliminating them. Quality management methods play an important role in the analysis and evaluation of errors.

Acknowledgment

This paper was written in frame of the work on the projects KEGA 013TUKE-4/2022 (50%) and VEGA 1/0485/22 (50%).

References

[1] Amrani, M.A., Alhomdi, M., Ghaleb, A.M., Al-Qubati, M., Shameeri, M. Implementing an integrated maintenance management system for monitoring production lines: a case study for biscuit industry. Journal of Quality in Maintenance Engineering. 28(1), 2020, 180–196.
[2] Berk, J., Berk, S. Quality management for the technology sector. Elsevier, Woburn, 2000.
[3] Best, M., Neuhauser, D. Joseph Juran: overcoming resistance to organisational change. BMJ Quality & Safety 15(5), 2006, 380–382.
[4] Bradley, J. R., Guerrero, H. H. An alternative FMEA method for simple and accurate ranking of failure modes, Decis. Sci., 42(3), 2011, 743–771.
[5] Carpitella, S., Certa, A., Izquierdo, J., La Fata, C. M. A combined multi-criteria approach to support FMECA analyses: A real-world case, Rel. Eng. Syst. Saf., 169, 2018, 394–402.
[6] Duarte, T.S., Maia, S.B.P., de Césares Martins, L., Mihailoff, B., Batista, L.C., Salvador, E.B., de Campos, B.P. Application of quality tools to reduce pneumatic leaks in the commercial vehicle brake system. SAE Brasil Congress & Exhibition, SAE Technical Paper, Sao Paulo, 2021, 1–9.

[7] Falk, B., Quattelbaum, B., Schmitt, R. Product quality from the customers' perspective–pystematic elicitation and deployment of perceived quality information. Proceedings of the Proceedings of the 6th CIRP-Sponsored International Conference on Digital Enterprise Technology., 2010, 211–222.
[8] Filz, M.-A., Langner, J.E.B., Herrmann, C., Thiede, S. Data-driven failure mode and effect analysis (FMEA) to enhance maintenance planning. Computers in Industry., 129(2021), 2021, 1–17.
[9] Hashemzahi, P., Azadnia, A., Galankashi, M. R., Helmi, S. A., & Rafiei, F. M. Green supplier selection and order allocation: a nonlinear stochastic model, International Journal of Value Chain Management, 11(2), 2020, 111–138.
[10] Jones, E. Quality management for organizations using lean six sigma techniques. 1st ed. CRP press, London, 2019.
[11] Kolenchukov, O.A., Petrovsky, E.A.: Analysis of the causes of failures of pyrolysis units. International Scientific Conference on Applied Physics, Information Technologies and Engineering., 1399(2019), 1–5.
[12] Kumar Sharma, R., Gopal Sharma, R. Integrating Six Sigma culture and TPM framework to improve manufacturing performance in SMEs. Quality and Reliability Engineering International., 30(5), 2014, 745–765.
[13] Li, B., Chen, R.-S., Liu, C.-Y. Using intelligent technology and real-time feedback algorithm to improve manufacturing process in IoT semiconductor industry. Journal of Supercomputing., 77(5), 2021, 4639–4658.
[14] Liu, H.-C. FMEA using uncertainty theories and MCDM methods. Springer, Singapore, 2016.
[15] Maged, A., Haridy, S., Kaytbay, S., Bhuiyan, N. Continuous improvement of injection moulding using Six Sigma: case study. International Journal of Industrial and Systems Engineering., 32(2), 243–266 (2019).
[16] Mitreva, E., Gjurevska, S., Taskov, N., Gjorshevski, H. Application of methods and techniques for free production in a company for manufacture of bread and bakery products. Quality – Access to Success., 20(171), 141–145 (2019).
[17] Montgomery, D.C. Statistical quality control. 6th ed. Wiley Global Education, New York, 2008.
[18] Parmenter, D. Pareto´s 80/20 rules for corporate accountants. 1st ed. John Wiley & Sons, New York, 2007.
[19] Rochman, D.D. Margana, R.R., Anwar, A., Ferdian, R. Application failure mode effect analysis on 3D printing Covid-19 face mask. Turkish Journal of Computer and Mathematics Education., 12(8), 2021, 1723–1728.
[20] Stamatis, D.H. Failure mode and effect analysis: FMEA from theory to execution. 2nd ed. Quality Press, Wisconsin, 2003.
[21] Tsarouhas, P. Reliability, availability and maintainability analysis of a bag production industry based on the six sigma DMAIC approach. International Journal of Lean Six Sigma., 12(2), 2020, 237–263.
[22] Vardeman, S.B., Jobe, J.M. Statistical methods for quality assurance: Basic, measurement, control, capability and improvement. 2nd ed. Springer, New York, 2016.
[23] Vulpes, T.C., Opran, C.G. Research on optimizing of the failure mode and effects analysis using advanced expert system. 4th international Conference. Progress on Polymers and Composites Products and Manufacturing Technologies, POLCOM, 396(2020), 1–4. Wiley-VCH GmbH, Romania, 2021.
[24] Westermeier, M., Reinhart, G., Steber, M. Complexity management for the start-up in lithium-ion cell production. 2nd International Conference on Ramp-Up Management, 20(2014), 13–19. Elsevier, Germany, 2014.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN–L 1584 – 2665