ISSN 1330-3651(Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230907000920
Preliminary communication

Analysis of Non-Conforming Production in an Engineering Company

Vladimira SCHINDLEROVA*, Jan MARCIK, Radek CADA, Ivana SAJDLEROVA

Abstract: In practice, there is a very often inaccurate recording of nonconforming production, resulting in waste and increasing wastefulness. This has a direct impact on the efficiency and profitability of production. This article deals with the analysis of non-conforming production in terms of the development of retained units for evaluation by the quality department and in terms of the development of scrap in a company involved in the production of tubes for the automotive and energy industries. The bottlenecks in the production process have been investigated and analysed, and the necessary measures have subsequently been determined. A new perspective on the issue of mismatched production was obtained, and new solutions were found that helped the company improve the efficiency of its production processes and thus increase its competitiveness. The analyses of non-conforming production presented in the paper are applicable in many enterprises. When the efficiency of production is increased, unnecessary losses are avoided. This will satisfy the philosophy of lean manufacturing, which aims to produce products in the shortest possible time with minimal cost.

Keywords: ABC analysis; non-conforming production; quality; quality tools

1 INTRODUCTION

Non-conforming production is very often called the Achilles heel of all manufacturing companies. In practise, incorrect recording of non-conforming production is very often carried out, resulting in waste in the production process and increased scrap [1]. Quality is already required in the production of semi-finished metal products [2]. For semi-finished products in the form of sheets, good formability is generally required [3-5]. High quality is required, especially for products for the automotive and energy industries [6, 7]. In case of high requirements for mechanical properties and fine grain values, sheets can be subjected to a continuous SPD process before final processing [8-10]. High quality is also required for products for medical purposes [11, 12]. The properties of machine parts can also be affected by welding [13-15], where the heat-affected region around the welded joint tends to be particularly problematic. The condition of the production equipment, which is influenced by its maintenance, also has a significant effect on the quality of the product [16-19]. In tube production, which is discussed further in the paper, the operations of forming, pressing, and heat treatment are in the production process [20, 21]. Improving manufacturing processes and procedures is a goal of all manufacturing companies and includes lean manufacturing principles, the use of dynamic simulation, and 3D technology as a tool for process improvement [22-25].

2 METODOLOGY

The term quality is often associated with non-conforming production and is defined differently depending on the area in which we operate. In practice, the term quality is used more in the field of production and is related to products. Quality is used in other areas of organisational management and in the service sector. There are many definitions of quality: Joseph M. Juran defines it as "fitness for use"[26], Philip B. Crosby defines quality as "compliance with requirements"[27], Armand Vallin Feigenbaum says "quality is what the customer thinks it is"[28], The ISO 9001 standard defines quality as "the degree of fulfilment of requirements by a set of embodied characteristics", Henry Ford said that "quality means doing the right thing even when no one is looking"[29]. From the above definitions, it can be seen that the common characteristics of quality include an understanding of the customer's requirement and the characteristics of the aggregate characteristics of products, services, people, and systems. It is also a source of material savings, and its level can be measured and improved. It is often associated with a management system that produces quality products that are appreciated by the customer or required by a standard or norm. It is also associated with the terms DMAIC improvement cycle, ISO 9001 Quality Management System, TQM Total Quality Management, OEE, or Six Sigma [30, 31].

Statistical process control (SPC) is the basis of quality management. It is a method of inter-operational control mainly in series production. By timely intervention in the process, the required product quality can be maintained. The purpose of statistical control is to try to determine whether changes occur in a production batch over a certain time interval due to a systematic phenomenon that would jeopardise the fulfilment of the quality requirement. The main tool for statistical process control is control charts, named after their creator, W. A. Shewhart. If the values are within the control limits, the process is considered stable. If the stability of the process is violated, corrective measures are taken to return the process to a stable state [32, 33].

Statistical Quality Control (SQC) is defined as the application of 14 statistical and analytical tools to monitor the output of the process. They are commonly referred to as basic and new quality tools. An overview of them is given in Tab. 1. Many of these tools are actively used in practice [33, 34].

Table 1 Basic and new quality management tools

Basic Quality Tools	New Quality Tools
Checklists	Affinity diagram
Paretorule	Correlation diagram
Flow chart	Systematic diagram (tree)
Cause and effect diagram	Matrix diagram
Histogram	Analysis of data in a matrix
Correlation diagrams	PDPCdiagram
Control diagrams	Network diagram

3 ANALYSIS OF NON-CONFORMING PRODUCTION IN THE COMPANY

A comprehensive analysis of mismatched production was carried out in a company that mainly produces pipes for the automotive and energy industries. In its more than 20 years of existence, it has become a trusted brand for industrially manufactured products. The company is part of the Senior plc, a multi-national holding group operating in 14 countries. The company's tube production can be divided into four main categories (see Fig. 1) flexible stainless steel tubes, steel tubes for internal combustion engine cooling systems, tubes for automotive sunroof controls, and tubes for the energy industry.

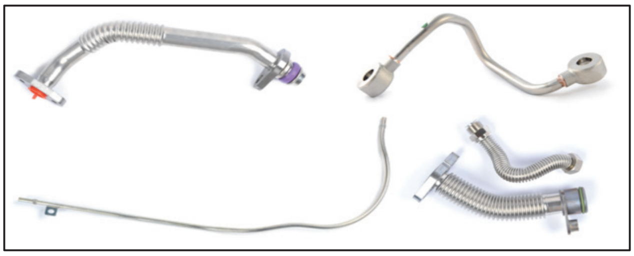

Figure 1 Basic types of pipes produced by the company [35]

3.1 Inspection of Parts During the Production Process

The inspection of products during the production process is carried out in each operation by an operator, a deputy foreman, or a member of the quality department. All necessary information such as required parameters, measuring instruments, and measurement frequency is described in the inspection plan. The inspection activities are kept in paper records on OK START sheets, and the measured values are entered manually. The checklists are then scanned and stored in the company's computer storage. Statistical process control (SPC) is again solved in the paper form of registered control cards, where operators manually enter values (Fig. 2). The employee then transcribes these cards into an Excel spreadsheet, and the process capability index C_{pk} is calculated, which is then entered into the regulatory card and the Excel spreadsheet and stored in the archive. This process can take up to a week, so it is not possible to monitor the data in real time or to analyse the actual process stability.

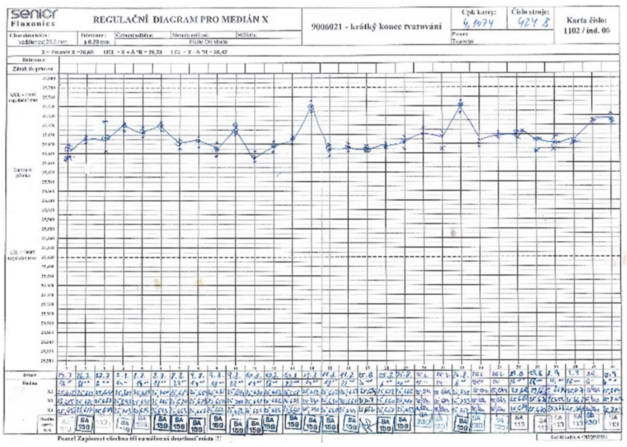

Figure 2 Sample control card for forming operation 2 on part 9006021 [35]

3.2 General Analysis of Non-Conforming Production

An operator usually detects a product defect during the operation in which the defect occurred or during one of the operations that the product undergoes during the production process. The operator then decides whether the product is a non-conforming piece (a part that has a seemingly irreparable defect), i.e., a product marked for disposal, or a problem that requires an assessment by a quality officer. The record of products that have been recorded and evaluated by quality officers is archived as of 2019. Fig. 3 shows the evolution of the number of retained pieces that have been returned to the process and the number of pieces that have been disposed of.

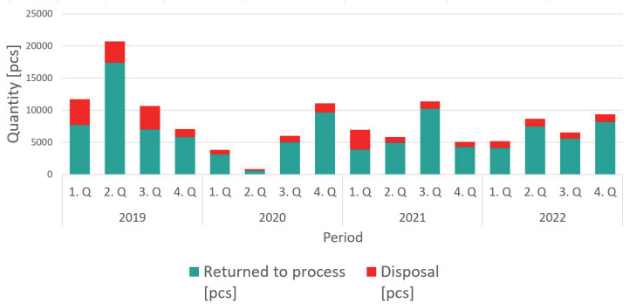

Figure 3 Evolution of the number of detainees for assessment by the quality department [35]

Most Frequently Assessed Parts (for 2022).

In this paper, a detailed analysis is performed for the year 2022. Using ABC analysis, the pieces most frequently retained for assessment were identified, representing 80% of the total number of pieces assessed. From Fig. 4, it can be seen that the vast majority of parts are returned to the process. The highest number of units for disposal was found for product 9006031. Tab. 2 shows that the most frequent defect was due to a non-compliance test with pressure, followed by other defects (defects not listed in the defect specimen) and defects in purchased parts.

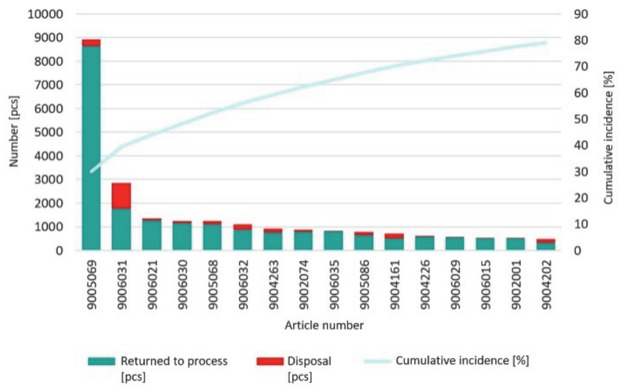

Figure 4 ABC analysis of 2022 retentions (Group A) [35]

Table 2 The first 3 defects of part 9006031 are the most frequently removed [35]

Order	Defect Name	Defect Code	Diposal [pcs]
1	Non-compliant pressure test	V62	1018
2	Other defects	V71	805
3	Defects of purchased parts	V98	574

A failing pressure test in pipes is most often caused by a leak in the casting. This problem originates with the supplier. An example of a leak is shown in Fig. 5.

Figure 5 Example of a casting leak (part9006031) [35]

The Most Common Defects in the Parts Assessed (for the year 2022).

On the basis of the previous analysis, the most common defects (Tab. 3) in the retained parts had to be identified. In the ABC analysis, only defects from groups A and B, which are the most frequent, are shown (Fig. 6). The analysis in Tab. 3 shows that the most frequent defects assessed by the quality department are in code V71 (Other Defects). It was analysed whether the defect detected by the operator is also the root cause of the non-conforming part. The diagram in Fig. 7 shows graphically the balance between the defects entered into the system by the operator (it is more of a consequence) and the root cause of the defect (detected by the quality officer) over a period of 4 months (from 1 September 2022 to 31 December 2022). For example, the defect most frequently evaluated (V71 Other Defects) reported by the operator is highlighted (on the left side of Fig. 7) and on the right side of Fig. 7 the analysis performed by the quality officer and the majority (up to 20 types) of root causes detected are coded in the defect template. Therefore, it is clear that the operator did not recognise the defect, which may be due to inadequate training

Table 3 ABC analysis of defects evaluated for 2022 (Groups A and B) [35]

Defect Name	Defect Code	Returned to process / pcs	Disposal / pcs	Group
Other Defects	V71	7931	858	A
Non-compliant Pressure Test	V62	3344	1262	A
Poor Position of the Holder	V48	3411	26	A
Defects in Purchased Parts	V98	1723	723	A
Spot Welding Defect	V47	1525	115	A
Wrong Bend Shape, Position, Rotation	V22	1070	311	A
Wrong Flange Flatness	V55	1069	22	A
Solder Overflow in the Functional Area	V54	903	96	B
Soldering Error (Pitch, Overflow, Amount of Solder, etc.)	V52	819	143	B
Non-compliantPressure Test	V64	725	132	B
Bumps, Scratches, and Deformations	V70	520	222	B
Shatter after Cutting, Drilling	V17	701	2	B
Incorrect Forming Dimension	V27	374	71	B

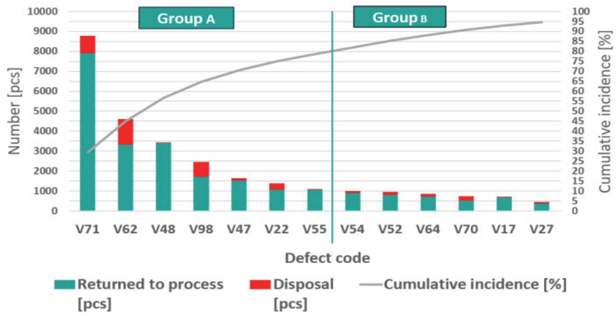

Figure 6 ABC analysis of retained defects for 2022 (Groups A and B) [35]

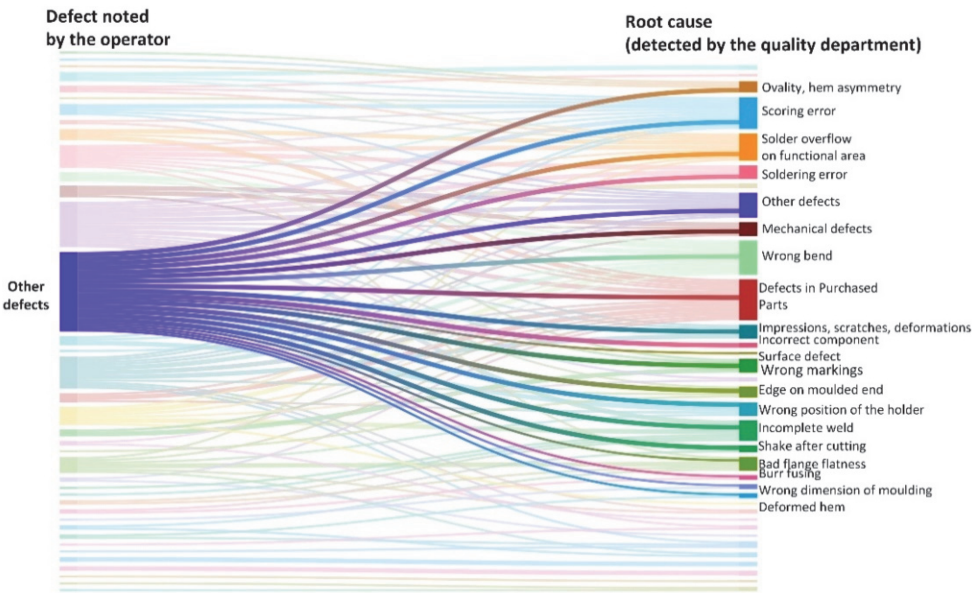

Figure 7 Root Cause Diagram of Defect V71 Other Defects [35]

Products Written off as "Junk" –Evolution over Time.

An important part of the analysis of mismatched production was also to look at products written off as "junk" over time. The information can be traced back to 2010 when the QAD information system was implemented in the company. An analysis of the most discarded units by product was performed (see Fig. 8).

Fig. 9 shows the evolution of the number of products written off as rejects and their financial value from 2016 to 2022. A downward trend is evident, which is in line with the company's objectives and policy to produce quality products.

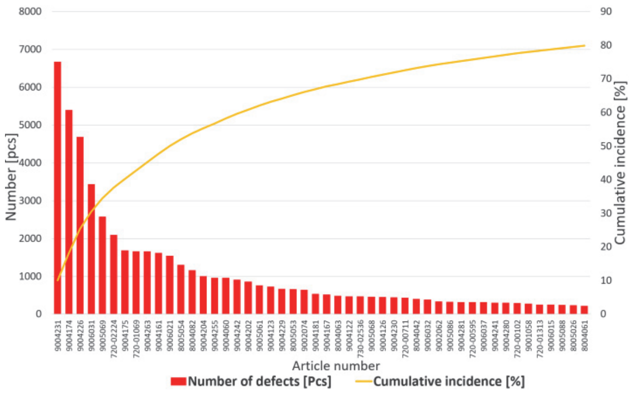

Figure 8 Most disposed parts [35]

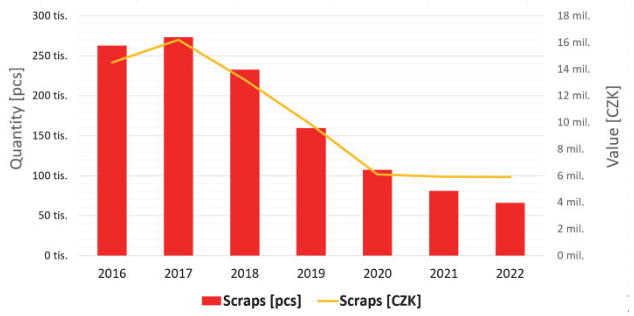

Figure 9 Products written as scraps: evolution over time [35]

Most Frequently Disposed Parts (for 2022).

The reasons for parts disposal are recorded in the information system. Based on this information, an analysis of the most common defects was performed. All defects are listed in a defect catalogue available to operators and quality personnel (Tab. 4).

Table 4 ABC analysis of write-offs for 2022 [35]

Defect Name	Defect Code	Disposal / pcs	Group
Adjustment	VS1	8245	A
Wall Corrugation, Bending Deformation	V21	6573	A
Defects in Purchased Parts	V98	6290	A
Wrong Bend –Shape, Position, Rotation	V22	3971	A
Wrong Ring Diameter	V25	3917	A
Missing Pieces	V72	3827	A
Bumps, Scratches, and Deformations	V70	3470	A
Unreported Rejects	NZ	2775	A
Insufficient Shaping	V12	2265	A
Prototype (Samples)	SP	1971	A
Defective Hem Diameter	V32	1711	A
Crack after Hydroforming	V14	1629	A
Cracked Hem	V35	1571	A
Other Defects	V71	1448	A
Wrong Hydroforming Diameter	V16	1311	A
Hole in Longitudinal Weld	V1	1091	A

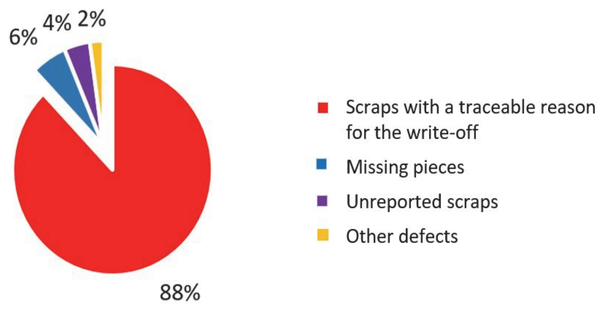

Figure 10 Parts with untraceable defects in the total number of rejects

The most frequently occurring defect was a wrong piece during machine setup (VS1). Again, the defect appears under the code V71 (Other Defects), V72 (Missing Pieces) and NZ (Unreported Rejects). For these parts, it is not possible to determine retrospectively what defect has occurred in the products, and they account for more than 12 % of the defective parts written off (see Fig. 10).

3.3 Product Selection for a More Detailed Analysis

More than 350 types of product are manufactured at the plant; therefore, an ABC analysis was performed for parts considered in the storage area and also an analysis for the products marked for disposal. Subsequently, we focused only on Group A and it was found that both analyses consistently included products that also represent a substantial part of the production programme (Fig. 11) and account for 24% of the total number of products analysed.

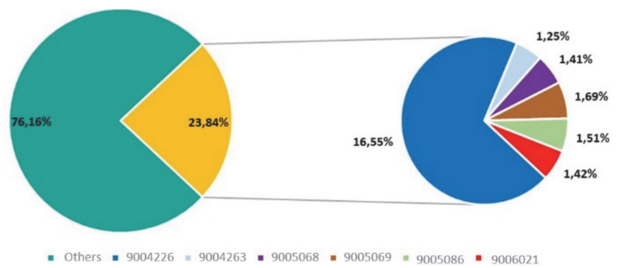

Figure 11 Percentage of products analysed from total parts produced [35]

Fig. 12 shows the proportion of parts analysed (17%) of the total number of parts scrapped.

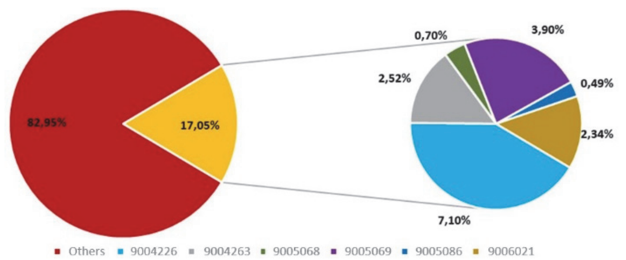

Figure 12 Percentage of parts analysed from the total amount of scrapped parts

The list of selected parts is given in Tab. 5, and their detailed description follows.

Table 5 Selection of parts analysed [35]

Part	Pipe Type
9 004 226	TOD
9 004 263	TOD
9 005 086	TOF
9 005 068	TCF
9 005 069	TCF
9 006 021	EGR

TOD - turbo oil drain. The pipes in this group are used to drain the oil from the turbochargers. They are thin-walled pipes and, as a result, parts of them are shaped using hydroforming technology, and other parts are shaped by conventional bending.

TOF - turbo oil feed. Tubular systems are used to feed oil into the turbochargers of internal combustion engines. These are thick-walled tubes.

TCF - turbo cooling fluid. Thick-walled tubing designed for internal combustion engine cooling systems.

EGR - exhaust gas recirculation. This is a category of thick-walled tubing designed to conduct exhaust gases within an engine assembly.

Further analyses revealed that the problem operations in which parts are written off are the bending operations (almost 2600 pieces), the hydroforming of the bellows and end cap (more than 1600 pieces), and the final operation where the pressure test is performed (almost 800 pieces). The effectiveness of the controls in the operations was found to be quite good. Most defects are detected when a defect occurs in a given operation or immediately in a subsequent operation.

3.4 Results of the Analyses

An evaluation of the information found (Tab. 6) was carried out from the above analyses.

Table 6 Evaluation of analyses [35]

Name of Analysis	Problem Area
Inspection of Parts During the Production Process	• Paper records of production controls and control chart cards. • Insufficient data analysis. • Risk of error in entering values when operators manually fill in forms.
General Analysis of Non-Conforming Production	• In the system records of discarded items, there are a large number of parts written off under the defect codes V71 (Other Defects), V72 (Missing Pieces) and NZ (Not Found Pieces). It is not possible to retrospectively identify the reason for the non-conformity for pieces written off under these defect codes. • Most write-offs occur during machine adjustment.
Analysis of Non-ConformingProduction of Selected Products	• Components can be written off systemically only on milestone operations. This distorts the records. • Defects in the system records of discarded parts are in some cases not recorded correctly. • The root causes of the defects and the operations that cause the defects cannot be determined from the system data.

3.5 Process Optimisation Design

Based on the problems found and identified, the following measures were recommended.

Introduction of a system for automatic data collection.

The company has a Keyence measuring machine that it uses to measure the lengths and profiles in the manufactured pieces. The instrument enables electronic data storage. Therefore, it was necessary to verify the suitability of the gauge using the GRR method for selected parts and operations. The results showed that the gauge was not capable of measuring most of the dimensions examined. The problem was mainly with the repeatability of the measurements. If the measured part is not clamped correctly, the measured values can vary significantly. Fig. 13 shows the cause of the measurement repeatability problems and the solution. After the problems were corrected, the capability analysis was performed again, and the measurement system was capable. The document describing the clamping of the part during the measurement was also updated, and instructions for measuring using the Keyence 2D gauge were issued.

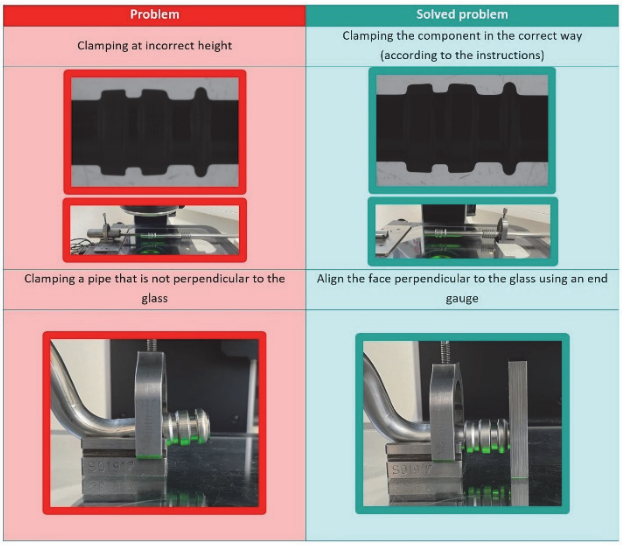

Figure 13 The most common causes of measurement repeatability problems and their solutions [35]

Training of staff, adding functions to the information system.

The analyses revealed that operators were incorrectly entering the codes for writing off items into the system, e.g. V71 (Other Defects), V72 (Missing Items), and NZ (Unreported Rejects). Therefore, notices of the results of the analysis were posted on the information boards in the hall, and all employees were made aware of the results. The possibility of adding a verbal comment to the defect record has been added to the information system, making it easier to identify a non-conforming product.

Improving records of discarded parts.

During the meeting with the operators, it was found that the operators were missing some types of defects in the formulary and therefore classified the defect as type V71 (Other Defects) (see Fig. 7). Subsequently, the quality officer identified some defects and assigned them to the appropriate defect type. Based on consultation with quality, technology, and operators, the defect template was completed and the V71 and V72 codes were removed. 11 new codes were added to the updated defect file. [35]

4 RESULTS AND DISCUSSION

From the results of the detailed analysis of non-conforming production in terms of the development of detained pieces for assessment by the Quality and Scrap Development Department, it is evident that correct recording and classification of defects are very important in the production process. The operator was found to contribute the most to defect identification. In the tube production analysed, operators often reported defect type V71 (Other Defects) because they were not properly trained.

The measuring equipment in the company was not used for automatic data recording; therefore, a verification of the capacity of the measuring device was recommended and carried out and methodological instructions were developed for the correct clamping and measurement.

Most of the problems identified in the company's pipe manufacturing process were named, some were completely resolved, and solutions were recommended for others (Tab. 7).

Table 7 Benefits of non-conforming production analysis for the company [33]

Identified Problem	Solution Status	Description
In the system records of discarded items, there are a large number of parts written off under the defect codes V71 (Other Defects), V72 (Missing Pieces) and NZ (Not Found Pieces).	Resolved	Defects have been added to the defect formulary: V73 - Insufficiently Soldered Part V74 - Missing Solder Ring V75 - Defective Crimping V76 - Does not Pass Through Camera V77 - Dropped Component after Bonding V78 - Leaky Joint after Assembly V79 - Damaged thermal protection V80 - Assembly Error, Shape, Position, Rotation V81 - Wrong Length, Long/Short Piece V82 - Missing Component V83 - Broken Part Defects have been removed from the defect formulary: V71 - Other Defects V72 - Missing Pieces
Defects are not recorded correctly in some cases.	Resolved	Operators were trained in correct entry of defects in the information system.
Production inspection and regulatory documentation records on paper.	Partially resolved	Partial replacement of paper records with electronic ones.
Root causes and operations that cause defects can only be estimated from the system data.	Solution proposal	It was recommended that the information system allows the addition of a verbal comment when describing a defect.
The largest number of write-offs occur during machine setup.	Not resolved	Management will address this in the next period.

5 CONCLUSION

The analyses of mismatch production presented in this paper are applicable in many enterprises. They allow one to find new solutions that will help to improve the efficiency of production processes, and thus increase the competitiveness of the enterprise. In the specific case described in the article, the analyses carried out allowed the authors to propose suitable solutions to increase the efficiency of production processes: The defects have been identified and described in more detail and have been added to the defect matrix table. In total, 11 types of defects have been added to the defect template table. Two types of defects, V71 and V72, were removed from the defect pattern. Based on the identified deficiencies, the quality department issued a warning about the types of defects that occur and their correct identification, and the production machine operators were given detailed training. The aforementioned warning was posted on information boards in the production hall. A record of the training of operators on possible defects has been kept, and regular meetings are subsequently held with operators to explain the types of defects and how to identify them correctly. When the efficiency of production is increased, unnecessary losses are avoided. This will fulfil the philosophy of lean production, which aims to produce products in the shortest possible time with minimum costs and to meet customer requirements with regard to the quality of the manufactured pieces. Further research will be directed towards the implementation of electronic defect registration and the design of new functions of the information system. The authors recommend that in the future defects should be recorded not only for the so-called milestone operations and that it should also be possible to add verbal comments when recording defects, which will contribute to the correct identification of the root cause of the defect and also to the identification of the operation in which the defect occurred.

Acknowledgements

The results of the contribution were achieved by solving the specific research project No. SP2023/020 with the name 'Research and Optimisation of Engineering Technologies' solved in 2023 at the Faculty of Mechanical Engineering of VSB – Technical University of Ostrava.

5 REFERENCES

[1] Hema, P., Paul, N. R. R., Cepova, L., Khan, B., Kumar, K., & Schindlerova, V. (2023). Complexity and Monitoring of Economic Operations Using a Game Theoretical Model for Cloud Computing. *Systems*, *11*(2).

[2] Velicka, M., Dittel, D., Pyszko, R., Prihoda, M., Vaculik, M., Fojtik, P., & Burda, J. (2013). Research of Thermal Processes for the Continuous Casting of Steel. *Materiali in Tehnologije*, *47(*6), 815-818.

[3] Cada, R. (1997). Formability of Deep-Drawing Steel Sheets. *Proceedings of the 5th European Conference on Advanced Materials and Processes and Applications (EUROMAT 97): Materials, Functionality & Design, 4, Characterization and Production/Design.* Sarton, L. A. J. L. & Zeedijk, H. B. (Eds.). Netherlands, Maastricht: Netherlands Society for Materials Science, 463-466.

[4] Evin, E., Tomas, M., & Vyboch, J. (2012). Prediction of Local Limit Deformations of Steel Sheets Depending on Deformation Scheme. *Chemical Journal*, *106*(S3), 401-404.

[5] Novak, V., Vales, M., Taticek, F., Sanovec, J., & Chrastansky, L. (2019). The Effect of Strain Rate on Position of Forming Limit Curve. *28th International Conference on Metallurgy and Materials (Metal 2019).*Ostrava, Czech Republic, TANGER, 450-454. https://doi.org/10.37904/metal.2019.825

[6] Cada, R. & Pektor, T. (2022). Design of Stamping Drawing Technology from Thin Sheet. *Proceedings of the 31st International Conference on Metallurgy and Materials (METAL 2022).* Brno, Czech Republic, TANGER, 262-267. https://doi.org/10.37904/metal.2022.4474

[7] Cada, R. & Matej, S. (2023). Solution of a Suitable Method of Production of Contactor Forgings. *MM Science Journal*, *16*(1), 6304-6313. https://doi.org/10.17973/MMSJ.2023_03_2022100

[8] Hilser, O., Rusz, S., Salajka, M., & Cizek, L. (2014). Evaluation of the Deep-Drawing Steel Sheets Processed by DRECE Device. *Archives of Materials Science and Engineering*, *68*(1), 31-35.

[9] Rusz, S., Hilser, O., Ochodek, V., Cada, R., Svec, J., & Szkandera, P. (2019). Influence of SPD Process on Low-Carbon Steel Mechanical Properties. *MM Science Journal*, *12*(2), 2910-2914

https://doi.org/10.17973/MMSJ.2019_06_201890
[10] Hilser, O., Rusz, S., Pastrnak, M., & Zabystrzan, R. (2020). Tensile Properties and Microhardness Evolution in Medium Carbon Sheets Subjected to Continuous SPD Process. *29th International Conference on Metallurgy and Materials (Metal 2020).*Ostrava, Czech Republic, TANGER, 339-343. https://doi.org/10.37904/metal.2020.3490
[11] Cada, R., Frydrysek, K., Sejda, F., Demel, J., & Pleva, L. (2017). Analysis of Locking Self-Taping Bone Screws for Angularly Stable Plates. *Journal of Medical and Biological Engineering*, *37*(4), 612-625. https://doi.org/10.1007/s40846-017-0279-4
[12] Cada, R., Frydrysek, K., Sejda, F., & Tiller, P. (2018). Evaluation of Locking Bone Screw Heads. *Proceedings of the 24th International Conference on ENGINEERING MECHANICS 2018.* Fischer, C. & Náprstek, J. (Eds.) Prague: Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences, 133-136. https://doi.org/10.21495/91-8-133
[13] Sternadelova, K., Mohyla, P., Trombik, M., & Krupova, H. (2019). Properties and Microstructure of Modeled Heat Affected Zone of P92 Steel. *28th International Conference on Metallurgy and Materials (Metal 2019)*. Ostrava, Czech Republic, TANGER, 832-836. https://doi.org/10.37904/metal.2019.843
[14] Tavodova, M., Naprstkova, N. Hnilicova, M., & Beno, P. (2020). Quality Evaluation of Welding Joints by Different Methods. *FME Transactions*. *48*(4), 816-824. https://doi.org/10.5937/fme2004816T
[15] Evin, E., Tomas, M., & Vyrostek, M. (2016). Laser-Beam Welding Impact on the Deformation Properties of Stainless Steels when Used for Automotive Applications. *Acta Mechanica Automatica*, *10*(3), 189-194. https://doi.org/10.1515/ama-2016-0028
[16] Necas, L. (2019). Training and Practice to Ensure Implementation of the TPM System. *MM Science Journal*, *12*(2), 4124-4127. https://doi.org/10.17973/MMSJ.2020_11_2020043
[17] Sajdlerova, I., Gregusova, M., & Schindlerova, V. (2015) Potential of Value Stream Mapping Utilization in the Seamless Steel Tubes Manufacturing Process. *24th International Conference on Metallurgy and Materials (Metal 2015).* Ostrava, Czech Republic, TANGER, 2056-2064.
[18] Necas, L. & Novak, J. (2021). Networking of Maintenance Entities for Production and Other Processes. *MM Science Journal.*, *14*(6), 5410-5413. https://doi.org/10.17973/MMSJ.2021_12_2021109
[19] Schindlerova, V. & Sajdlerova, I. (2017) Influence of tool wear on material flow. *Advance in Science and Technology Research Journal*, *11*(1), 161-165. https://doi.org10.129 13/22998624/66507
[20] Cada, R. & Losak, P. (2021). Optimization of Bellows and Tubes Cutting by Disc Knife to Achieve the Minimum Burr Size. *MM Science Journal*, *14*(6), 5373-5380. https://doi.org/10.17973/mmsj.2021_12_2021104
[21] Cada, R. & Losak, P. (2021). Comparison of Deburring Technologies after Pipe Cutting. In: *Proceedings of the 30th Anniversary International Conference on Metallurgy and Materials (METAL 2021).* Brno Czech Republic, TANGER, 585-591. https://doi.org/10.37904/metal.2021.4161
[22] Zakaria, N. H., Mohamed, N. M. Z. N., Rahid, M. F. F., & Rose, A. N. M. (2017). Lean Manufacturing Implementation in Reducing Waste for Electronic Assembly Line. *2nd International Conference on Automotive Innovation and Green Vehicle (AiGEV),* 90. https://doi.org/10.1051/matecconf/20179001048.
[23] Sproch, F. & Nevima, J. (2021). Use of Smart 3D Printing Technology in Conventional Engineering Production to Detect and Prevent the Occurrence of Defects. *MM Science Journal*, *14*(6), 5441-5447.
[24] Tureckova, K. & Nevima, J. (2020) The Cost Benefit Analysis for the Concept of a Smart City: How to Measure the Efficiency of Smart Solutions? *Sustainability*, *12*(7), 2663. https://doi.org/10.3390/su12072663
[25] Schindlerova, V. & Sajdlerova, I. (2020). Use of the Dynamic Simulation to Reduce Handling Complexity in the Manufacturing Process. *Advances in Science and Technology Research Journal*, *14*(1), 81-88. https://doi.org/https://doi.org/10.12913/22998624/113616.
[26] Juran, J. M. (2020). *The History of Quality*.
[27] OpEx Learning Team. (2019) *Philip Crosby: Contributions to The Theory of Process Improvement and Six Sigma.*
[28] Feigenbaum, V. A. (1991). *Total Qality Control*. McGraw-Hill Companies.
[29] Ford, H. (2020). *My Life and Work.* Createspace Independent Publishing Platform.
[30] Bucko, M., Schindlerova, V., & Krupova, H. (2022). Application of Lean Manufacturing Methods in the Production of Ultrasonic Sensor. *Technicki Vjesnik*, *29*(5), 1671-1677. https://doi.org/10.17559/TV-20220421141917
[31] Sajdlerova, I., Schindlerova, V., & Kratochvil, J. (2021). Potential and Limits of OEE in the Total Productivity Management. *Advances in Science and Technology Research Journal*, *14*(2), 19-26.
[32] Stieberova, B. (2017). *Statistical regulation.*
[33] ASQ. (2023). *What is statistical process control?*
[34] Gayathri, R., Rani, S. U., Cepova, L., Rajesh, M., & Kalita, K. (2022). A Comparative Analysis of Machine Learning Models in Prediction of Mortar Compressive Strength. *Processes, 10*(7) 1387. https://doi.org/10.3390/pr10071387
[35] Marcik, J. (2023). *Analysis of Non-conforming Productionin the Engineering Company: Bachelor's Thesis*. Ostrava: VSB Technical University of Ostrava. Faculty of Mechanical Engineering. Department of Mechanical Technology, Thesis Head: Schindlerova, V.

Contact information:

Vladimira SCHINDLEROVA, PhD
(Corresponding author)
Faculty of Mechanical Engineering, VSB Technical University of Ostrava,
17. Listopadu 2172/15, 708 00 Ostrava Poruba. Czech Republic
E-mail: vladimira.schindlerova@vsb.cz

Jan MARCIK, BC.
Faculty of Mechanical Engineering, VSB Technical University of Ostrava,
17. Listopadu 2172/15, 708 00 Ostrava-Poruba. Czech Republic
E-mail: jan.marcik.st@vsb.cz

Radek CADA, prof.
Faculty of Mechanical Engineering, VSB Technical University of Ostrava,
17. Listopadu 2172/15, 708 00 Ostrava-Poruba. Czech Republic
E-mail: radek.cada@vsb.cz

Ivana SAJDLEROVA, PhD
Faculty of Mechanical Engineering, VSB Technical University of Ostrava
17. Listopadu 2172/15, 708 00 Ostrava-Poruba. Czech Republic
E-mail: ivana.sajdlerova@vsb.cz