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PRIORITIZING PRODUCT QUALITY PROBLEMS USING QUALITY MANAGEMENT TOOLS

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Abstract: In today's competitive business environment, effectively analyzing, evaluating, and resolving product quality problems is critical to maintaining customer satisfaction, reducing financial losses, and preserving a company's reputation. This study prioritizes internal and external quality problems in paperboard packaging using selected quality management tools. Product quality problems are categorized based on their frequency of occurrence and financial losses. Three quality management tools are used: the Pareto-Lorenz diagram, the matrix data analysis diagram, and the box plot. The Pareto-Lorenz diagram identified the key quality problems that generate the highest number of events and the greatest financial losses, consistent with the 80/20 rule. The matrix data analysis diagram divided the quality problems into four groups based on their combined impact, indicating critical problems for both categories. The box plot identified outliers and extremes, revealing quality problems with significantly higher frequency and financial impact than others. All quality tools used identified the overprint complaint with code 403 as critical. The results highlight the effectiveness of the quality management tools used in prioritizing product quality problems.
Keywords: quality management, quality tools, quality problems, statistical data analysis

1. INTRODUCTION

In today's highly competitive business environment, maintaining high standards of product quality is essential to the success, sustainability, and growth of any organization. Failure to meet product quality requirements can lead to significant financial losses, customer dissatisfaction, and reputational damage, requiring organizations to quickly and effectively analyze and resolve quality problems (Hansen and Bush, 1999; Biadacz R., 2024). As organizations strive for continuous improvement, the ability to quickly analyze, assess and prioritize quality problems plays a critical role in effectively directing resources and taking corrective actions in the most critical areas (Tomic and Spasojević-Brkić, 2011; Thunyachairat et al 2024).

Product quality is the level to which a product meets the customer's requirements; it is all of its features and properties that affect its ability to satisfy a given need (Garvin, 1984; Milan and Vysloužilová, 2023). Product quality problems include deviations from established quality standards that affect the product's ability to meet customer requirements (Hamrol, 2024). Product quality problems can occur at any stage of the product life cycle, from design and production to distribution and use, and often have significant consequences for both the company and the consumer (Webber and Wallace, 2012). Product quality problems manifest themselves as product nonconformities and defects, and products with such problems are called nonconforming or defective products. Nonconforming product is a product that fails to meet one or more specified requirements, standards, or desixgn specifications but may still function as intended (Hamrol, 2024). Defective product is typically one that is not only nonconforming but also fails to perform its intended function, rendering it unusable or unsafe (Sadikin, 2023). Defective products often lead to significant repercussions, including customer dissatisfaction and potential liability problems for manufacturers (Battini et al., 2012).

Product quality problems are classified as internal or external depending on where they are detected (Hamrol, 2024). Internal product quality problems are nonconformities identified within an organization before the product reaches the customer. They are detected through internal quality control procedures, audits, or inspections during the production process. Addressing these problems internally helps organizations prevent defective products from entering the market, reducing the potential for customer dissatisfaction. External product quality problems, on the other hand, refer to quality problems discovered after the product has been delivered to the customer or introduced to the market. These problems, often reported through complaints or returns, not only affect the perception of quality by customers but also pose a greater risk to the reputation and financial stability of the company. External product quality problems can result in higher costs associated with product recalls, replacements, or legal implications (Webber and Wallace, 2012; Hamrol, 2024).

Product quality problems require effective quality management strategies to minimize their occurrence and mitigate the risks associated with them (Dorf, 1998). Quality management tools can play a important role in this process by enabling organizations to systematically analyze, assess and resolve product quality problems (Bamford and Greatbanks, 2005). In addition, selected tools can be used to prioritize quality problems based on quantifiable data, such as frequency of occurrence and associated costs, ensuring that corrective actions are focused on critical quality problems. Quality tools' key roles are for quality management and continuous improvement (Ciecińska and Oleksiak, 2023; Gejdos, 2023; Tarí and Sabater, 2004; Tashi et al., 2016).

This article presents the use of selected quality tools to prioritize quality problems for a specific product. The study aims to show how to analyze and assess product quality problems to identify critical ones and determine the direction of corrective actions, using quantitative data on the frequency of occurrence and the amount of financial loss they caused.

2. RESEARCH METHODOLODGY

The aim of the study is to apply selected numerical quality management tools to the analysis of internal and external quality problems of corrugated packaging in order to prioritize for both quality problems and corrective actions.

The study focuses on a corrugated packaging manufacturer producing 3- and 5-layer packaging using grey, white and coated white paper, using hot glue and tear tapes. Data for the analysis of product quality problems was taken from an annual register of packaging complaints, compiled in an Excel file. Complaints in the company are classified as internal or external. Internal complaints refer to problems identified within the organization by quality control teams or employees assigned to inspection tasks, while external complaints are those reported by customers. Both types cause measurable financial losses for the company. A total of 35 different complaints, both related and unrelated to production, were identified during the analysed year (Knop and Ziora, 2022). Table 1 provides an overview of all identified complaints related to corrugated packaging, their codes and detailed description.

Table 1. Quality problems related to cardboard packaging

Code	Complaint type	Detailed description
101	Raw material quality	The quality of the raw material influencing the processes related to its processing
102	Tools	Tools missing or damaged
201	Packaging molding / construction	Improper packaging formation, poor design
301	Creases	No creases or improper placement of creases, weak creases
302	Lack of paper on the edge	There is no paper on the edge of the sheet
303	Sheet format	Wrong sheet format
304	The quality of the cardboard surface	Uneven surface, paper wrinkles, grater, kinks between wave crests, blisters
305	The quality of cardboard gluing	Inadequate sticking of cardboard, delamination
306	Cardboard curve	Curvature, warping of cardboard
401	Punching elements	Rotary die cutter missing or misplaced, frayed edges and gaps, flat die punch defects
402	Gluing packages	Improper gluing of the packaging
403	Overprint	Improper print, smudged print, underprints; wrong color
404	Product marking	Product marking not in accordance with the customer's requirements
405	Packing	Packaging not in accordance with the customer's requirements, bad strapping, lack of foil, Pallets not in accordance with the production order, etc.
406	Cracking	Cardboard cracking on creases or during cutting
407	Size of the package	Incorrect packaging dimensions
408	Crushed cardboard	Incorrect waveform, damage during production
409	Wrong layout on the sheet	Wrong arrangement of the print or pattern on the sheet in relation to the print, reverse wave direction
410	Quantity	Quantitative defect
411	Tape	Bad placement, bad incision
412	Palette	Wrong size pallets, damaged pallets, wrong number of pallets on delivery note, etc.
413	Machinery	Technical condition of machines
414	Barcode	Code unreadable, unprinted on the bar code
501	Spoilage on the Magazine of Finished Products (MFP)	Unable to find goods on MFP

502	Spoilage after inventory	No goods after inventory at MFP
503	Wrong: delivery / documents	Incorrect delivery documents or delivery errors
504	Damage	Damage during storage or transport, getting wet
505	Spoilage on PR	Unable to find goods on PR
701	Incorrect data in CPMS	Incorrect data entered into CPMS, incorrect quantities
702	Communication	Bad flow of information, lack of information, false information, no contact
703	Confused batch	Confused papers
704	Price	Price inconsistent with the commercial offer
705	Cooperation	The complaint is recognized for the good of cooperation with the client
900	Other complaints	
901	Tests	Product development, first launch

The product quality problems were assessed by examining the number of complaint events and the financial losses they caused, with a focus on both internal and external quality problems (Knop and Ziora, 2022). To analyze these problems and prioritize improvement actions, three quality tools from the category of tools were employed: "traditional/classic/basic," "new/management and planning," and "statistical," all based on quantitative (numerical) data. The tools used included the Pareto-Lorenz diagram, the matrix data analysis diagram, and the box plot.

The Pareto-Lorenz diagram was used to indicate critical external and internal complaints of cardboard packaging due to the number of complaint events recorded during the year and the losses incurred by the company in connection with these complaints expressed in PLN. One critical complaint was indicated, generating the largest number of occurrences and the largest financial losses, and complaints belonging to the so-called group "A" (the most important), which were identified according to the ABC principle and were responsible for approximately 80% of the effect (occurrences, losses).

The Pareto-Lorenz diagram is an analytical qualitative tool from the group of 7 basic qualitative tools for analyzing and assessing quality problems (Pacana and Czerwińska, 2020; Knop, 2015). This diagram helps identify the most frequent quality problems during the analyzed research period and prioritize those that should be addressed first. The Pareto-Lorenz diagram is based on the "80-20" rule, which states that a small proportion of causes (typically 20–30%) often account for the majority (70–80%) of the effects. (Dumitrascu, 2024; Jagusiak-Kocik, 2023). The analysis of results from the Pareto-Lorenz diagram uses the ABC principle, which helps to focus attention on key aspects requiring priority treatment. The ABC principle in the analysis of results from the Pareto-Lorenz diagram consists in classifying the analyzed elements (e.g. problems, costs) into three groups according to their impact on the whole, which allows for setting priorities in action. Based on the cumulative impact (e.g. number of events, costs), the elements are divided into groups A, B, and C (Knop, 2021). Group A (the most significant elements) constitutes about 20% of the analyzed elements, which are responsible for about 80% of the effect. The line on the Lorenz curve corresponding to a maximum of 80% of the impact indicates the boundary between group A and the rest. Group B (moderately important elements) comprises the next 30% of the elements, which are responsible for about 15% of the effect. The line on the Lorenz curve corresponding to a maximum of 95% of the impact indicates the boundary between group B and the rest. Group C (the least important elements) constitutes about 50% of the analyzed elements, which generate only 5% of the effect. The line on the Lorenz curve corresponding to a value greater than 95% of the impact indicates the boundary between group C and the rest (Sitko et al., 2021; Czerwińska and Pacana, 2021). The use of the Pareto-Lorenz diagram allows organizations to prioritize quality problems, effectively directing improvement efforts toward the most critical quality problems (Stasiak-Betlejewska and Czajkowska, 2017).

A matrix data analysis diagram was utilized to stratify data on the share of internal and external complaint occurrences and the associated financial losses into four categories, as well as to identify the critical category with the highest overall share.

Matrix data analysis is a multivariate analysis technique also known as "principal component analysis." (Nayatani et al., 2006). This is the only method within the seven new tools that is based on data analysis and gives numerical results (ASQ). The purpose of this tool is to systematically examine and quantify relationships between two or more groups of data or variables. This diagram is suitable for prioritizing problems because it helps identify critical problems that require immediate attention by assessing their relationship to key categories (e.g., share of occurrences versus costs) (Tague, 2005). The diagram supports the selection of multiple options by comparing their potential impact or importance across criteria (Mizuno, 1988; Andrássyová et al., 2013).

The box plot was used to illustrate the structure of the data on the number of complaint events and their associated financial losses in order to identify unusual values, so-called outliers and extreme values, that differ significantly from other observations. These unusual values will indicate unusual complaint cases with a significantly higher number of events and financial losses than the others.

A box plot, one of the statistical tools (Simanová and Gejdos, 2015), is a graphical tool used to visualize the distribution of data, its variability, and to identify unusual (outlier or extreme) values. This diagram allows to quickly assess key features of a data set, such as central tendency, spread, and skewness. Identifying outliers and extreme values in a box plot involves detecting observations that deviate significantly from the typical distribution of the data (Williamson et al., 1989; Polańczyk et al., 2024). A box plot displays key statistical elements such as quartiles, median, and ranges, which allows you to easily locate untypical values (Mazarei et al., 2024). The first step in identifying outliers in a box plot is to calculate the first quartile (Q1) and third quartile (Q3) of the data, which divide the data set into four equal parts, where Q1 is the value below which 25% of the data fall, and Q3 is the value below which 75% of the data fall. Then, it should be calculated the interquartile range (IQR), which is the difference between Q3 and Q1 ($IQR=Q3-Q1$), indicating the range in which the middle 50% of the data fall. Based on the IQR, it is determined the limits that define the range in which the typical values fall: the lower limit as $Q1-1.5\times IQR$ and the upper limit as $Q3+1.5\times IQR$. Values that are less than the lower limit or greater than the upper limit are considered outliers and are visualized in the box plot as points outside the "whiskers." To identify extreme values, more stringent limits are used by calculating the lower extreme limit as $Q1-3\times IQR$ and the upper extreme limit as $Q3+3\times IQR$, and values outside these limits are treated as extreme. In a box plot, outliers are marked as points outside the whiskers using a circle symbol, and extreme values are marked with asterisk symbols (Marmolejo-Ramos and Tian, 2010; Krzywinski and Altman, 2014).

TIBCO Statistica 13.3 and Excel software were used as a data analysis tools.

3. RESULTS AND DISCUSSION

An analysis was carried out of external and internal complaints regarding cardboard packaging identified over a period of one year in terms of the number of complaint incidents and the value of losses caused by these complaints.

Figure 1 presents a Pareto-Lorenz diagram used to analyze the percentage structure of external complaint events concerning cardboard packaging.

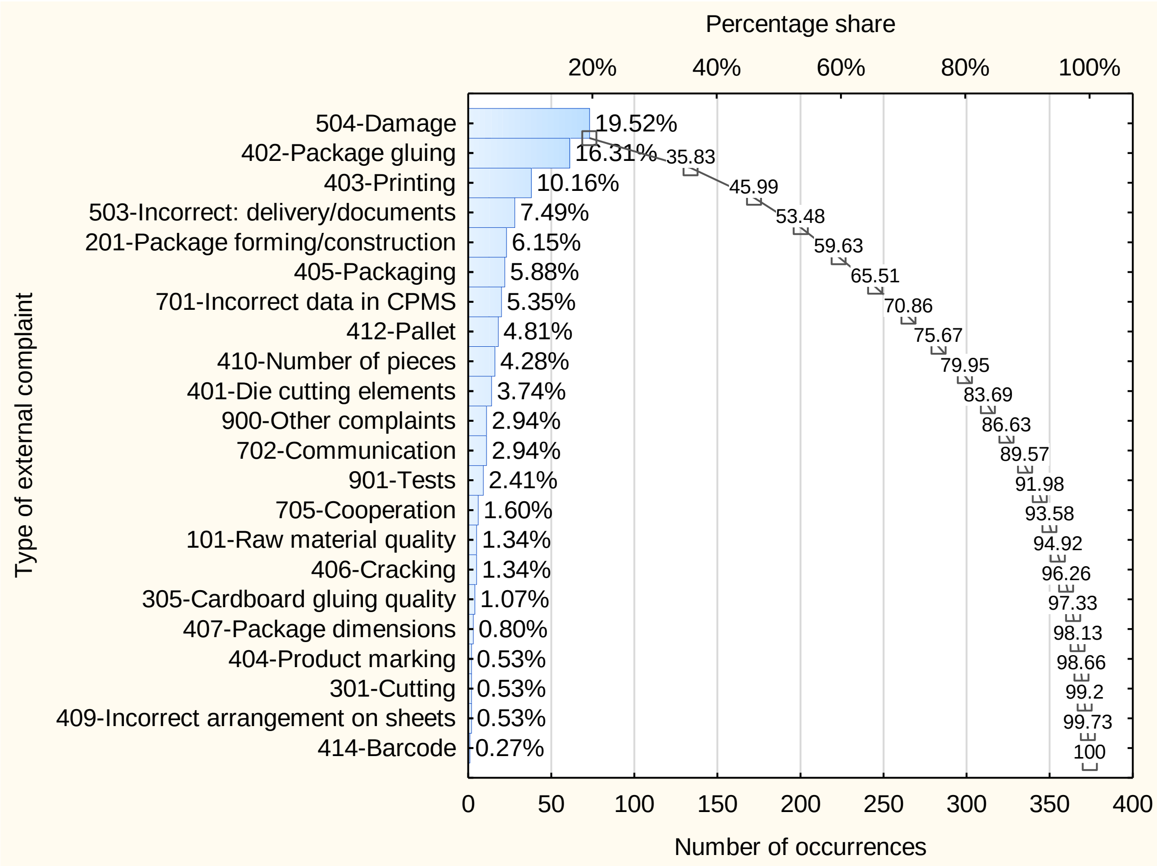

Fig. 1. Pareto-Lorenz diagram showing the distribution of external complaint events

The Pareto-Lorenz diagram showed that the most critical external complaint in terms of the number of complaint events was the complaint with code 504—damage (19.52%). Damage to cardboard packaging occurs during storage, transport, or as a result of moisture. 9 types of external complaints out of 21 (37.5%) generated a total of 79.95% of complaint events. The group of critical external complaint events includes complaints with codes: 504, 402, 403, 503, 201, 405, 701, 412, 410.

In summary, the analysis using the Pareto-Lorenz diagram highlighted that the most critical external complaint, in terms of the number of complaint events, was code 504—damage, accounting for 19.52% of total complaints.

Figure 2 presents the Pareto-Lorenz diagram used to analyze the percentage structure of internal complaint events regarding cardboard packaging.

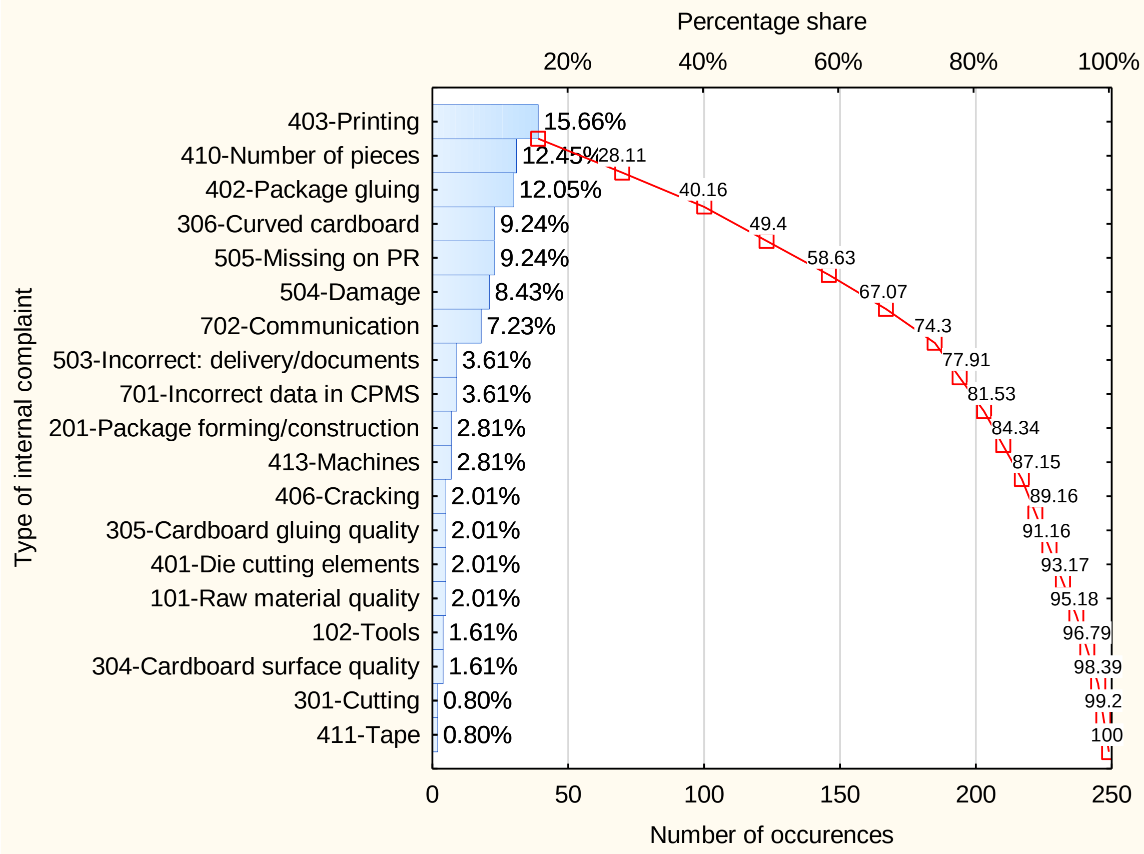

Fig. 2. Pareto-Lorenz diagram showing the distribution of internal complaint events

As can be seen from Figure 2, the critical internal complaint for cardboard packaging was the complaint with code 403—printing. This complaint was related to incorrect printing, blurred printing, incomplete printing, and the wrong colour of cardboard packaging. 7 out of 19 internal complaints (36.84%) resulted in a total of 77.91% of complaint incidents. The group of critical internal complaint events includes complaints with codes: 403, 410, 402, 306, 505, 504, 702.

In summary, the analysis using the Pareto-Lorenz diagram highlighted that the most critical internal complaint, in terms of the number of complaint events, was code 403—printing, accounting for 15.66% of total complaints.

A matrix data analysis diagram was used to classify all cardboard packaging complaints according to the share of external complaint events and the share of internal complaint events, and to identify critical complaints with respect to these two categories together (quarter IV) (Fig. 3). In order to divide all complaints into four quarters, a common division was applied for both categories, based on the maximum value of one of the categories (19.52% for external complaint events) and on this basis ranges were created for both categories, specifying the division criterion in this case as 20% (the closest overall percentage value).

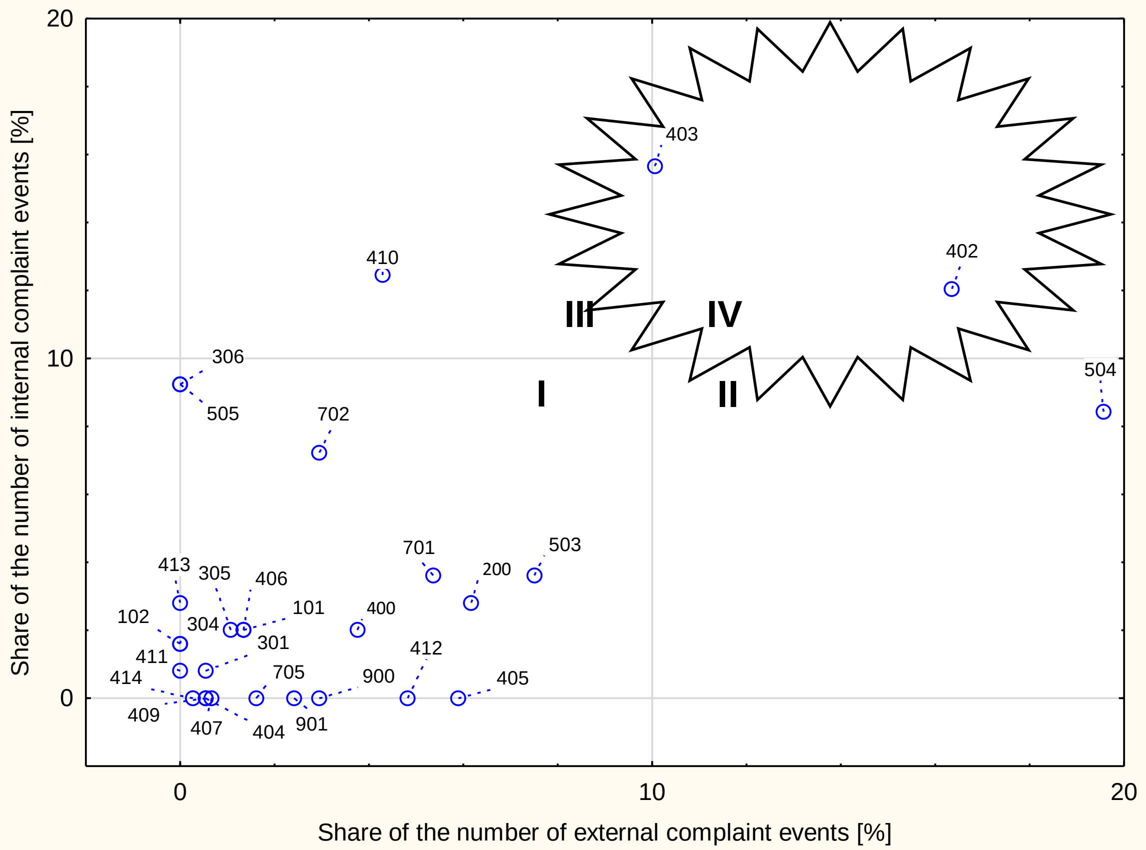

Fig. 3. Matrix data analysis diagram comparing the share of external complaint events to the share of internal complaint events

Based on the matrix data analysis diagram, complaints about cardboard packaging were classified into four quarters according to the share of the number of external complaint events and the share of the number of internal complaint events (Table 1), in order to indicate critical complaints - with the highest share of the total number of internal and external complaint events (quarter IV).

Table 1. Classification of cardboard packaging complaints into four quarters based on the share of external and internal complaint events

Quarter of matrix data analysis diagram	**I: Complaints with a relatively low share of internal events and a relatively low share of external events**	**II: Complaints with a relatively low share of internal events and a relatively high share of external events**
Complaint code	101, 102, 200, 304, 305, 306, 400, 404, 405, 406, 407, 409, 411, 412, 413, 503, 505, 701, 702, 900, 901	504
Quarter of matrix data analysis diagram	**III: Complaints with a relatively high share of internal events and a relatively low share of external events**	**IV: Complaints with a relatively high share of internal events and a relatively high share of external events (critical quarter)**
Complaint code	410	402, 403

Critical complaints about cardboard packaging in terms of the total share of internal and external complaint events are complaints with codes 402—gluing packages and 403—

printing. Complaints marked with code 402 are caused by incorrect gluing of the packaging, while those marked with code 403 are caused by incorrect printing, blurred printing, incomplete printing, or the wrong colour of cardboard packaging. The complaint characterized by a relatively low share of internal events and a relatively high share of external events was the complaint with code 504—damage caused as a result of storage, transport or wetting of packaging. The complaint with a relatively high share of internal events but a relatively low share of external events was a complaint with code 410—quantitative defects. The remaining types of complaints belonged to quarter I, which indicated a relatively low share of internal and external complaint events. These were therefore complaints with the lowest elimination priority index due to the lowest share of complaint events.
In summary, the analysis using the matrix data analysis diagram based on the total share of internal and external complaint events identified critical complaints in cardboard packaging, particularly those with codes 402—gluing packages and 403—printing, as they exhibited the highest overall shares.
A matrix matrix analysis diagram with box plots was used to identify outlier and extreme complaint values in terms of the number of internal and external events (Fig. 4).

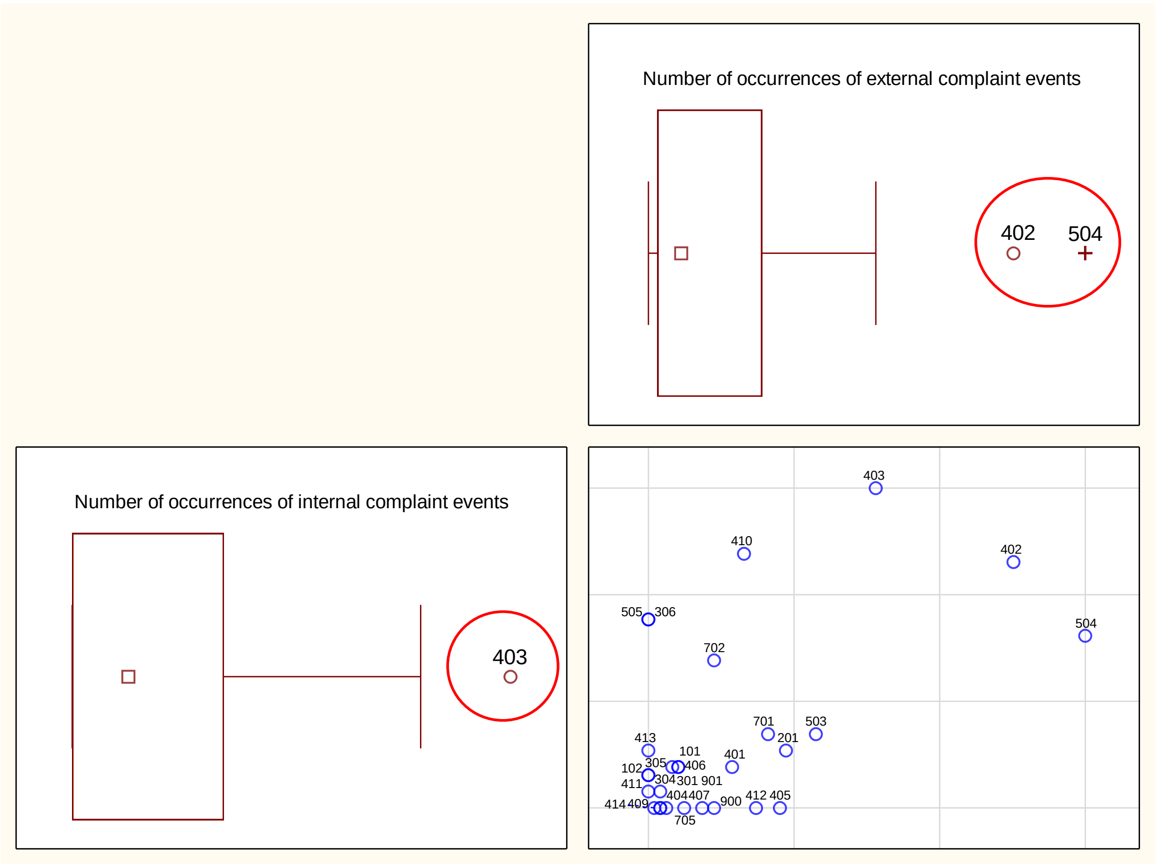

Fig. 4. Matrix data analysis with box plots comparing the number of occurrences of external complaint events to the number of occurrences of internal complaint events

When analyzing the number of internal complaint events, complaint code 403 should be distinguished as atypical. The number of complaints assigned to this code significantly differs (is significantly higher) from the values for other complaint codes. In the case of external complaints, code 402 can be considered atypical, while code 504 should be

classified as extreme. Both of these codes are characterized by a significantly higher number of events compared to other complaint codes.
In summary, matrix diagram with box plots identified outliers and extremes in the number of occurrences of internal and external complaint codes (402, 403, 504) that require action to reduce their number. These complaint codes had a significantly higher frequency of occurrence compared to other codes.
The Pareto-Lorenz diagram was used to analyze the share of the value of losses incurred by the enterprise due to external complaints (Fig. 5).

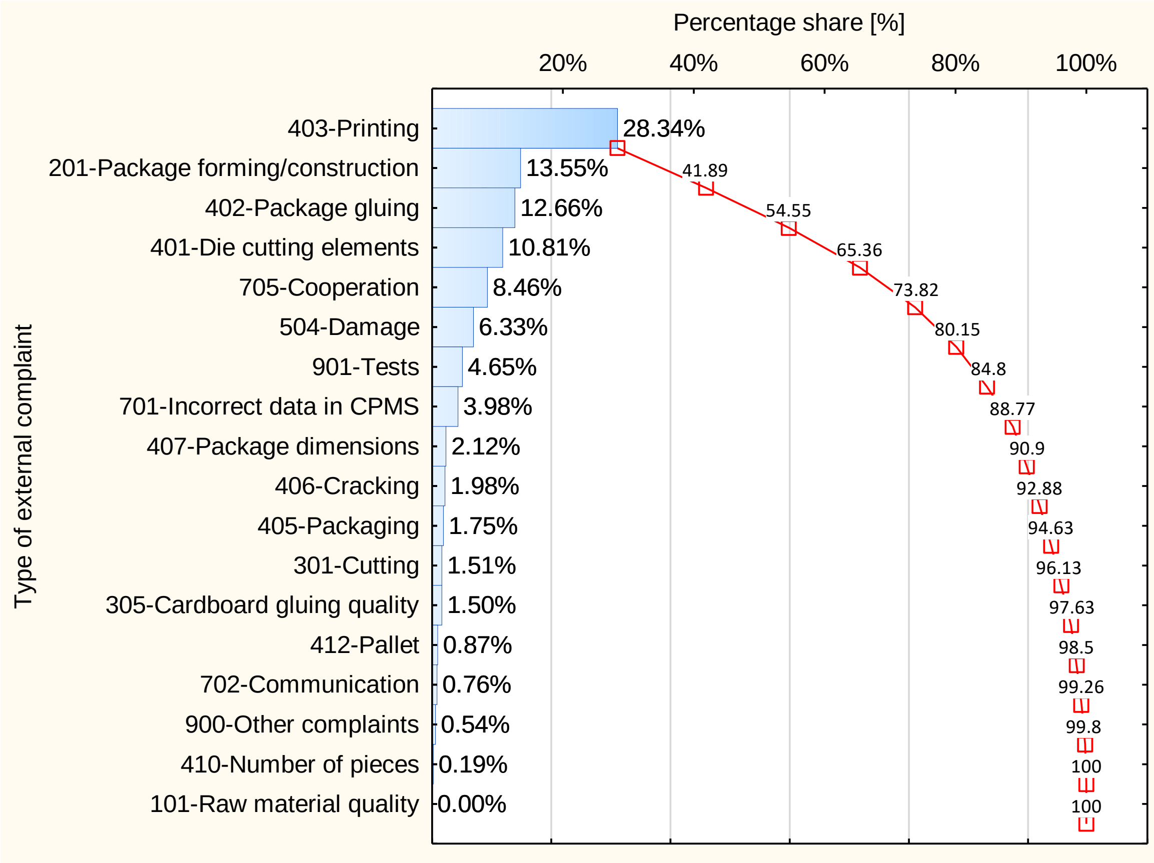

Fig. 5. Pareto-Lorenz diagram showing the distribution of losses incurred by the company due to external complaints

The Pareto-Lorenz diagram showed that the critical external complaint in terms of the share of losses generated for the surveyed company was the complaint with the code 403—printing (28.34%). 5 external complaints out of 18 (27.78%) generated a total of 73.82% of complaint losses. The most significant external complaints were those with the code: 403, 201, 402, 401, 705.
In summary, the analysis using the Pareto-Lorenz diagram showed that the most significant external complaint in terms of the value of losses incurred by the company was the complaint marked with code 403–printing, which accounted for 28.34% of all complaints.
The Pareto-Lorenz diagram was used to analyze the share of the value of losses incurred by the enterprise due to internal complaints (Fig. 6).

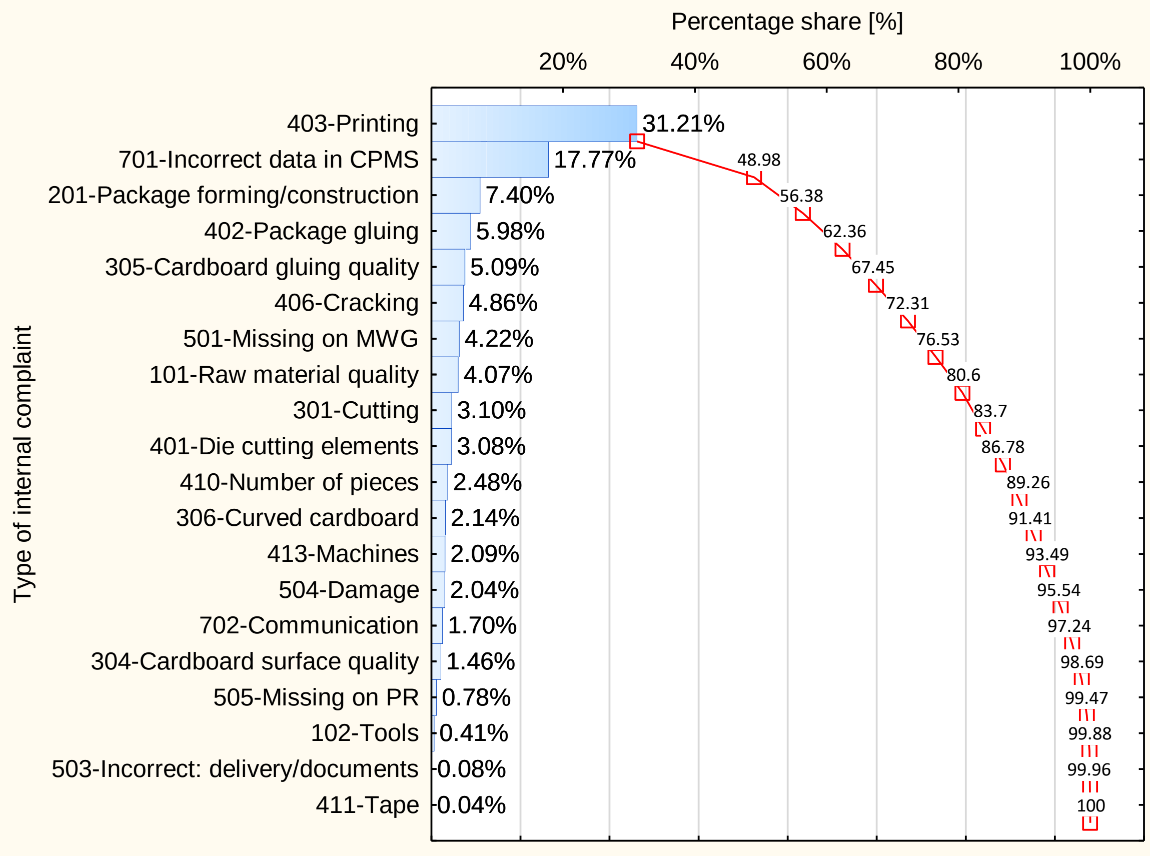

Fig. 6. Pareto-Lorenz diagram showing the distribution of losses incurred by the company due to internal complaints

The Pareto-Lorenz diagram showed that the critical internal complaint in terms of the share of losses generated for the surveyed company was the complaint with the code 403—printing (31.21%). 7 internal complaints out of 20 (35%) generated a total of 76.53% of complaint losses. The most significant internal complaints were those with the code: 403, 701, 201, 402, 305, 406, 501.

In summary, the analysis using the Pareto-Lorenz diagram showed that the most significant internal complaint in terms of the value of losses incurred by the company was the complaint marked with code 403–printing, which accounted for 31.21% of all complaints.

A matrix data analysis diagram was used to classify all cardboard packaging complaints according to the share of the losses incurred by the company due to internal complaints and share of the losses incurred by the company due to external complaints, and to identify critical complaints with respect to these two categories together (quarter IV) (Fig. 7).

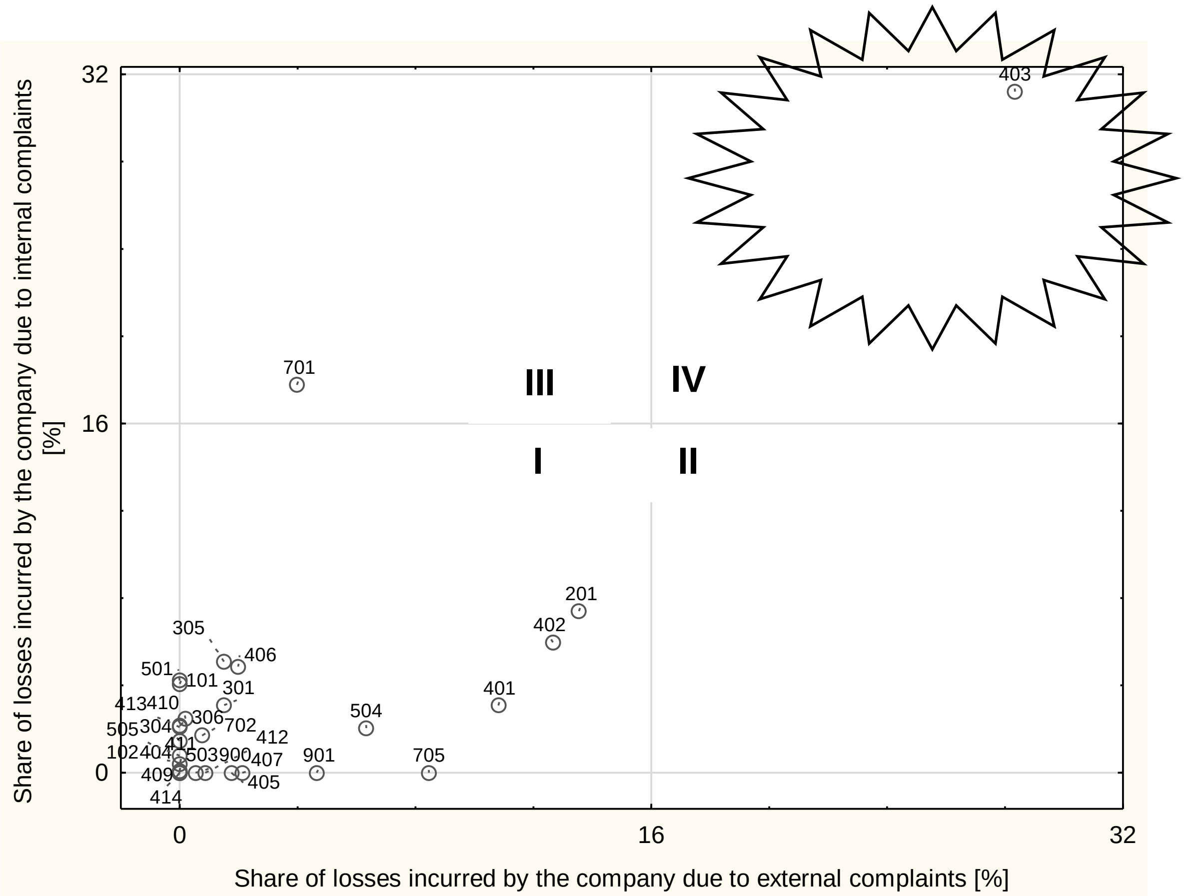

Fig. 7. A matrix data analysis diagram comparing the share of losses incurred by the company due to internal complaints with the share of losses caused by external complaints

Table 2 was created based on Figure 7. Table 2 presents the classification of cardboard packaging complaints into four quarters, based on the matrix diagram and the proportion of losses incurred by the company from internal complaints compared to those from external complaints.

Table 2. Classification of cardboard packaging complaints into four quarters based on the share of losses incurred by the company due to internal complaints versus external complaints

Quarter of matrix data analysis diagram	**I: Complaints with a relatively low share of both internal and external losses**	**II: Complaints with a relatively low share of internal losses and a relatively high share of external losses**
Complaint code	101, 102, 201, 301, 304, 305, 306, 401, 402, 404, 405, 406, 407, 409, 410, 411, 412, 413, 414, 501, 503, 504, 505, 702, 705, 900, 901	-
Quarter of matrix data analysis diagram	**III: Complaints with a relatively high share of internal losses and a relatively low share of external losses**	**IV: Complaints with a relatively high share of both internal and external losses (critical quarter)**
Complaint code	701	403

The complaint regarding a relatively high share of internal and external losses was coded 403–overprinting. A complaint with a relatively high share of internal losses and a relatively low share of external losses is a complaint with code 701–incorrect data in CPMS. The remaining complaints belong to the quarter with complaints with a relatively low share of internal and external losses.
In summary, the analysis using a matrix data analysis diagram based on the total losses due to internal and external complaints identified the critical complaint for cardboard packaging with code 403–overprinting, as it showed the highest overall combined loss share.
Fig. 8 shows a matrix diagram with box plots comparing the share of losses incurred by the company due to internal complaints versus those resulting from external complaints.

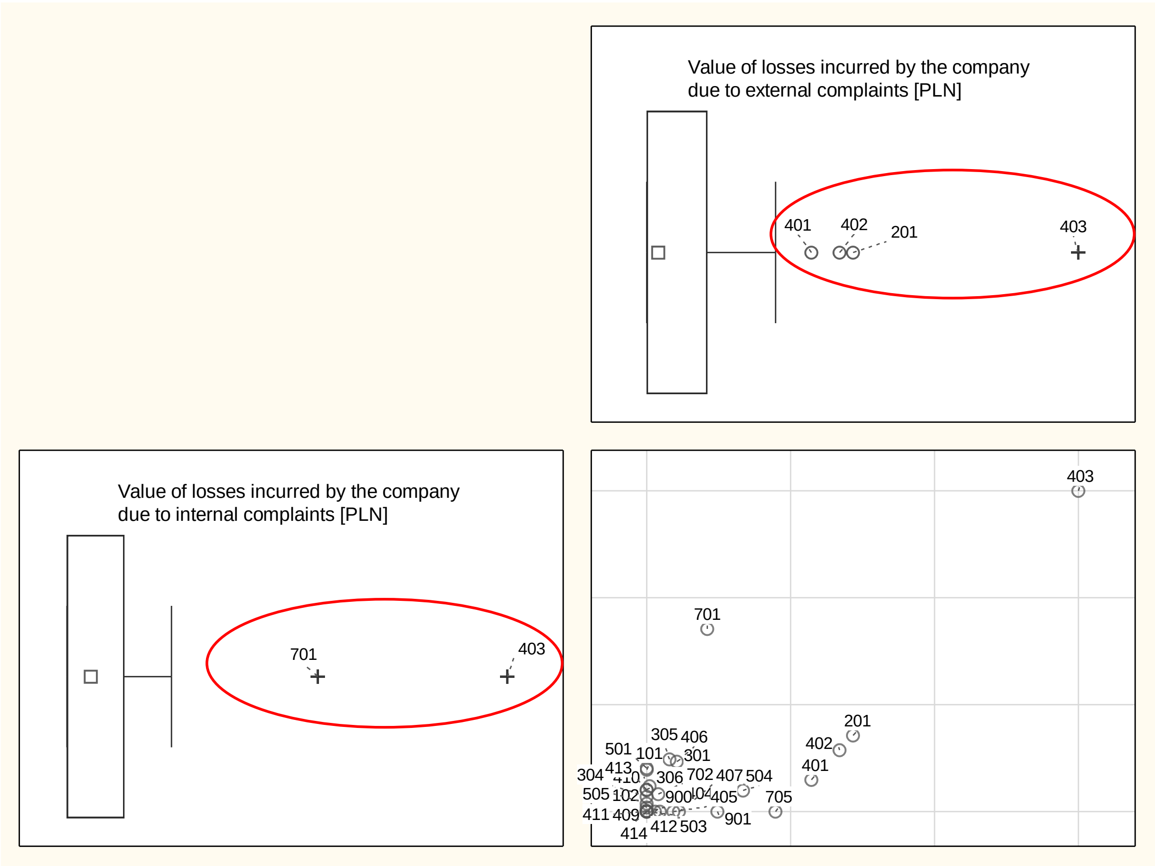

Fig. 8. A matrix data analysis diagram with box plots comparing the share of losses incurred by the company due to internal complaints versus those caused by external complaints

When analyzing internal complaint losses, complaint codes 701 and 403 should be considered extreme. For external complaints, codes 401, 402, and 201 should be regarded as outliers, while complaint code 403 should be classified as extreme. The analysis shows that the most critical external and internal complaint in terms of the value of the losses generated for the company is the complaint with code 403.
The identification of these extreme and outlier codes helps pinpoint specific problem areas in both internal and external processes. By focusing on the most critical problems (extreme complaints), the company can better allocate resources to mitigate the root causes of these problems.

In summary, the matrix analysis diagram with box plots identified outliers and extreme values in the loss share of internal and external complaint codes (201, 401, 402, 701, 403) that require action to reduce their impact on losses. These complaint codes had significantly higher occurrence loss values compared to other codes.

4. CONCLUSION

Analysis of internal and external complaints regarding corrugated packaging revealed the significant role of quality management tools in identifying and prioritizing quality problems. Using the Pareto-Lorenz diagram, matrix data analysis diagram, and box plot, this study provided a systematic approach to assessing the frequency and financial impact of complaints, thereby enabling the identification of critical quality problems. The Pareto-Lorenz diagram effectively highlighted the most influential complaints in terms of frequency of occurrence and financial loss. Complaints with codes 402 (glue problems), 403 (overprint defects), 504 (damage) were found to be the most critical, accounting for a significant portion of incidents and financial losses. Similarly, the matrix data analysis diagram enabled detailed categorization of complaints by priority levels, helping to focus corrective actions on areas with the highest combined share of internal and external non-conformities due to the number of events and financial losses - complaints with codes 402, 403. In addition, box plots facilitated the detection of complaints with outliers and extreme values in terms of the number of complaint events and the value of generated financial losses – complaints with codes 201, 401, 402, 403, 504, 701. To sum up all the analyses, it should be stated that improvement actions in the studied company should be directed primarily at reducing the occurrence of complaints with code 403 – problems with printing (improper print, smudged print, underprints, wrong color), due to the most frequent occurrence of this complaint as critical in the analyses performed using quality tools.

The results emphasize the importance of data-driven prioritization in quality management. Organizations can use these tools to prioritize quality problems, which allows resources to be more efficiently allocated to address the most urgent problems, thereby reducing the time wasted on resolving low-impact problems.

Quality problem prioritization allowing organizations to focus on the most important areas for improvement. However, this process is not without risks that can impact the effectiveness of the actions taken and the achievement of the intended results. For example, focusing on the highest priority problems may result in less urgent but equally important problems remaining unresolved. Problems previously considered less important may become more critical due to changes in the market or technology, requiring regular updating of priorities. Overreliance on analytical tools without considering the business context may also lead to incomplete or erroneous conclusions. The results of a Pareto analysis may indicate one problem as critical, when in fact several smaller problems have a greater cumulative impact. In summary, effective quality problem prioritization requires a balanced approach that takes into account both objective data and the broader organizational context.

Future research could extend this approach by examining the integration of additional quality tools or applying this framework to other industries or product categories. Additionally, future studies could investigate the use of artificial intelligence (AI) tools in conjunction with quality tools to streamline data analysis and decision-making, further improving the efficiency and effectiveness of quality management practices.

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