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MULTIVARIATE NONCONFORMITY ANALYSIS FOR PAVING STONE MANUFACTURING PROCESS IMPROVEMENT

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Abstract:
The article presents the result of multidimensional analysis of 'Behaton' type paving stones' nonconformities for improving the production process by improving the quality of the final product. Statistical tools, including SPC tools and quality tools, both basic and new, were used to analyse nonconformities in the spatial-temporal system, i.e. according to the type of nonconformity and according to the examined months. The purpose of using the data analysis tools was to thoroughly analyse the cases of nonconformities of the tested product, obtain information on the structure of these nonconformities in the various terms, and information on the stability and predictability of the numerical structure of nonconformity over time. Potential causes influencing a large percentage of paving stone defects were identified, factors and variables influencing the most frequently occurring nonconformities were determined, and improvement actions were proposed. As a result of the multidimensional and multifaceted analyses of paving stone nonconformities, it was shown that in the structure of nonconformity there were cases that were unusual in terms of the number of occurrences, and the lack of stability in the number of nonconformities in terms of the examined months was proven. Three critical nonconformities of the tested product were identified: side surface defects, vertical edge defects, and scratches and cracks. It was determined that the most important factor causing a large percentage of nonconformity was the time of shaking and vibrating the concrete, which was significantly related to the technical condition of the machines, and the most important reason for a large percentage of paving stone nonconformity was the lack of efficient maintenance. Machine, method, and man turned out to be the most important categories of problem factors and specific remedial actions were proposed. A multidimensional look at the structure of paving stone nonconformity as well as the factor and causes causing them has brought a lot of valuable information for the management staff of the analysed company, thanks to which it is possible to improve the production process and improve the quality of the final product.

Key words: *SPC tools, QC tools, nonconformity analysis, statistical analysis, improvement*

INTRODUCTION

Nonconformity is defined as the non-fulfillment of a requirement [1]. Nonconformities could involve procedural or process deviation, product characteristic deviation from specification, product defect, customer or supplier return, or any other, specific to organization [2]. Management of nonconformity is a set of policies and procedures for identifying, documenting, evaluating, segregating and disposing of products that do not conform to the manufacturer's specific requirements [3]. In nonconformity management, a critical area is the investigation of nonconformities in order to identify their causes or causes and take action to avoid their recurrence [4]. The introduction of the necessary and appropriate corrective and preventive actions is a prerequisite for the permanent elimination of non-conformities from the production process [5]. Actions taken should be appropriate to the actual or potential effects of the nonconformities and the magnitude of the problem [6]. The analysis of nonconformities can be made in terms of the numerical structure of the occurrence of these nonconformities for a given period of time or the cost structure, i.e. taking into account the costs that nonconformities generate for the plant [7]. Including both, the numerical and cost structure in the nonconformity analysis for a given period of time can identify critical nonconformity or nonconformities that the establishment should address first [8]. An analysis of the structure of nonconformities over time, with other factors unchanged, can provide useful information for managers on the effectiveness of corrective and preventive actions [9].

Thanks to such an analysis, company managers can determine how well they are coping with specific, detected nonconformities and with the elimination of potential nonconformities in the production process. In order to analyse the structure of nonconformities, companies can use classic and new quality tools [10], including statistical tools classified as SPC [11], such as the Ishikawa diagram, Pareto-Lorenz diagram, and control chart [12]. Statistical process control (SPC) is a systematic decision making tool which uses statistical-based techniques to monitor and control a process to advance the quality or uniformity of the output of a process – usually a manufacturing process [13]. The main goal of statistics is to obtain the most useful and generalized information on the studied phenomenon from the data set [14]. For this purpose, statistical research is carried out, and then the data obtained in this way are subjected to statistical analysis. The use of descriptive statistics methods allows for summarizing a data set and drawing some basic conclusions and generalizations about the studied set [15]. Statistical analyses in the area of production and quality have the advantage over other analyses in that they are based on real data taken from the production process, which are a real reflection of what is happening in such a process. Proper analysis of data in the area of production and quality supported by a graphical presentation of the results allows the managers to better understand the process, identify its strengths and weaknesses, and better manage process variation. Managers to improve the production process can use this kind of information obtained from the process.

The aim of the article is a multidimensional analysis of the paving stone nonconformities structure with the use of statistical tools, including SPC tools and new quality tools in order to improve the paving stone production process in the studied company.

LITERATURE REVIEW

Quality is a certain degree of excellence and is one of the important factor in realization of the production process [16]. Improvement can be explained as a goal-achieving activity. Dynamically changing environment, progressive technological development, increasing intensity of competition and threats of crisis phenomena require the continuous improvement of production processes and management systems [17]. Continuous improvement is the most effective way for manufacturing and service organisation to improve performance, efficiency, quality and competitiveness [18]. The right improvements can reduce defects, decrease production time, and boost client satisfaction [19, 20]. There are many problems faced by manufacturing companies today, e.g. poor product quality, but companies often do not understand the root causes of these problems and are unable to identify them [18]. Deviations in desired quality or specific client requirements in a process or system are referred as nonconformities [1]. The organization is required to fix the detected nonconformities, identify their causes, plan and implement corrective action to eliminate the causes of nonconformities [21]. Early detection of nonconformities should be seen as an opportunity for improvement [22]. The use of information hidden in nonconformities about their type, number of occurrences, level of importance for the internal and external client, place of detection, effectiveness of its detection, relationship between a given case and other cases allows for better management of specific cases of nonconformities and taking effective corrective actions. If a nonconformity is detected, each company should be able to analyse the root cause of the problem, find a solution and prevent future events [23, 24]. For in-depth analysis of nonconformities and searching for the sources of nonconformities, it is recommended to use statistical tools, including SPC tools and quality tools, both basic and new [25]. Seven statistical process control (SPC) tools (known also as basic quality tools) are: Pareto-Lorenz diagram, Process Flow Diagram, Cause and Effect/Ishikawa diagram, Check sheets, Histogram, Scatter diagram, Control charts [26, 27]. Control charts, as one of the SPC tools, are important tools used to monitor a process, to ensure the process is in a state of statistical control and thus reducing nonconformities level and improving product quality [13]. The basic 7/SPC tools are effective for data analysis, process control and quality improvement when we have mainly numerical data [28]. The new quality tools, known as the seven management and planning tools (MPs) or simply the seven management tools, are specially designed for non-numeric data, to organize this type of data, generate ideas (e.g. from brainstorming), to streamline planning , to eliminate errors and assist in resolving problems and nonconformities [29]. The 7 new tools include: Affinity diagrams, Tree diagrams, PDPC, Matrix diagrams, Dependency digraphs, Prioritization matrices, Activity network diagram [30]. The use of basic and new tools allows for a methodical and orderly approach to the analysis of data and problems of various types, obtaining information about their nature, root causes of problems, which allows the management staff to deal with these problems more efficiently and effectively [31].

RESEARCH METHODOLOGY

The examined company is a paving & construction company from the SME category located in the Silesian Voivodeship in Poland. The company mainly produces paving stones. Paving stone is a prefabricated building element intended for the construction of a surface layer, made by vibro-pressing of unreinforced, un-coloured, or coloured concrete, one or two-layer concrete, characterized by a shape that allows the elements to stick to each other [32]. It is made of concrete, which includes cement of brand 45 (in the amount of 400 kg/m^3) and washed sand and aggregate with a grain size of 1÷4 mm [33]. The examined product, with regard to which the nonconformities structure was analysed, was a 'Behaton' concrete paving stone. 'Behaton' cobblestones, also known as the double T type, are, due to their shape, one of the first cobblestones ever produced [32]. 'Behaton' paving stones are very popular in large industrial areas due to the low purchase cost, very good load transfer, and quick and rational execution [33].

The data for the analysis of paving stone nonconformity were taken from the quality control department of the examined company. In the annual period, 14 types of paving stone non-compliance were identified, which were given the designations from N_1 to N_{14},
where:
N_1 – Side surface defects,
N_2 – Vertical edge defects,
N_3 – Scratches and cracks,
N_4 – Pigmentation,
N_5 – Irregular texture,
N_6 – Fractures,
N_7 – Gaps and defects of corners,
N_8 – Stain, soil water permanent,
N_9 – Irregular color,
N_{10} – Incompatible beveling,
N_{11} – High grindability,
N_{12} – Incompatible size: length,
N_{13} – Incompatible size: wide,
N_{14} – Incompatible size: high.
The number of paving stone nonconformities occurrence is presented in the Table 1.

Table 1
Summary of the number of occurrences of paving stone nonconformities in the period of 12 months in the studied company – the base for the statistical analysis

Designation	Research period [month]											
	1	2	3	4	5	6	7	8	9	10	11	12
N_1	793	580	742	680	690	620	710	715	624	680	620	590
N_2	471	360	420	580	576	490	420	575	594	540	535	410
N_3	350	265	355	420	410	432	367	412	412	390	415	320
N_4	299	198	280	330	280	315	315	356	340	320	310	245
N_5	242	156	251	290	241	287	289	204	290	275	280	193
N_6	151	121	190	140	130	212	220	170	215	190	172	156
N_7	120	110	178	135	128	165	178	135	195	156	125	149
N_8	102	105	120	98	115	115	110	98	175	120	114	121
N_9	96	100	110	82	110	98	103	85	100	115	105	118
N_{10}	62	59	98	70	80	92	71	74	35	100	83	98
N_{11}	32	28	56	29	69	65	43	28	21	57	75	76
N_{12}	17	23	24	15	22	49	20	14	15	20	35	32
N_{13}	13	15	15	9	15	19	15	10	11	16	20	19
N_{14}	11	9	10	4	12	16	12	8	9	10	15	10

The data collected for the analysis of nonconformities will be subjected to statistical analysis in the spatial-temporal system, i.e. according to the types of nonconformities (spatial system) and according to subsequent months (time system). In order to statistically analyse the structure of nonconformities in both systems, basic statistical measures will be used first, i.e. mean ($X_{av.}$), range (R), standard deviation (s), first quartile (Q_1), third quartile (Q_3), coefficient of variation (V_s) [34].
The classic median-quartile-range box-whisker plot, in Tukey's version, which shows the whiskers as 1.5 IQR (Inter Quartile Range), will be used. Then the values of the minimum and maximum values, if they are different, will go beyond the whiskers and will represent elements that differ from the rest of the population (the so-called outliers). The 3IQR distance value will indicate the extreme values in the sample [14, 15, 35]. This plot will be used to analyse the distribution of nonconformity data in the two systems and identify outliers.
A box-whisker plot of the mean-standard deviation type [15, 35] will be used to illustrate the distribution of position and variability measures for the values of the occurrence of individual types of nonconformity in both systems.
One of the picture charts, i.e. Chernoff's faces [36], will be used to illustrate the relationship between the numbers of occurrences of all types of nonconformities in the examined months of the year. In the method of this face, individual variables are reflected by different characteristics of the human face [36]. To the shapes and sizes of the individual face expressions were attributed relative amounts of all nonconformities for the each month.
The face expression that represent the following nonconformities are:
N_1: face wideness,
N_2: the position of ears,
N_3: the position of the face-half,
N_4: the eccentricity of the upper half of the face,
N_5: the eccentricity of the down half of the face,
N_6: the length of the nose,
N_7: the position of the middle part of the mouth,
N_8: mouth distortion,
N_9: the length of mouth,
N_{10}: the high of eye line,
N_{11}: the distance between eyes,
N_{12}: the eyes ramp,
N_{13}: the eyes eccentricity,
N_{14}: the half-length of eyes.
The Pearson correlation coefficient and the correlation matrix will be used to determine the degree of dependence between the numbers of occurrences of particular types of nonconformities. The correlation coefficient is a statistical measure of how strongly two data interact. The higher the correlation coefficient, the greater the likelihood that two different values will behave similarly [15, 37].
A control chart for individual values and a moving range was used to assess the stability of the number of nonconformities over a 12-month period. Individuals and moving range charts are used to monitor individual values and the variation of a process based on samples taken from a process over time (hours, shifts, days, weeks, months, etc.) [11, 13]. By using this chart, it can be spotted variability that falls outside of what would be considered "normal" – indicating a special cause of variation and a need for investigation and possible process adjustment [38].
The Pareto-Lorenz diagram will be used to comprehensively present the number of inconsistencies for the year under study. The Pareto-Lorenz diagram, also known as the ABC method, the law of non-uniformity of distribution, or the law of 20-80, is used to identify and assess the significance of the analysed issues [39]. The Pareto-Lorenz

diagram will be used to indicate the critical nonconformity in terms of the frequency of occurrences. It will also point to those inconsistencies that generated approx. 80% of quality problems, according to the so-called Pareto rules, 20/80.

In order to show logical connections between the groups of factors influencing the problem of a high percentage of paving stone shortages, a new quality tool will be used, i.e. the matrix diagram. A matrix diagram is used for analysing and displaying the relationship between two or more data sets. It was used L-shaped matrix diagram to compare two sets of data in a two-dimensional Table [29, 30, 31]. It was established that the analysis with the use of the matrix diagram will concern the 7 most common nonconformities of paving stones and the 7 most important factors influencing the formation of these nonconformities. Because of the analysis, it will be determined whether there is a relationship between the analysed nonconformities and the selected factors. In the absence of a relationship between the nonconformity and the factor, the value "0" will be selected, in the case of a relationship, the strength of a given impact will be assigned a value from 1 to 5,

where:

5 – strong impact,

3 – average impact,

1 – weak impact.

One of the classic quality tools, also known as the SPC tool, the Ishikawa diagram, will be used to identify the causes of a high percentage of paving stone nonconformities. The Ishikawa diagram, or the fishbone diagram, is a visual representation of the causes and effects of the analysed problem. The task of the Ishikawa diagram is to discover, collect and classify (in terms of the importance of the impact) the causes of the analysed problem [26, 27, 28]. The collected information on the reasons for the nonconformity of the paving stones was obtained through brainstorming with people from the production department, technology department and quality department, as well as from the company's management. The 5M principle was used to break down the listed causes of nonconformity into common causal categories.

RESULTS

Table 2 presents a summary of the results of the calculation of statistical measures for the data on the number of occurrences of particular types of nonconformities in the studied 12 months.

The box-and-whisker plot for a synthetic analysis of the structure of the number of occurrences of paving stone nonconformities in all months was presented in Fig. 1.

With the successive index of nonconformities, the scope of the variability of nonconformities decreased because the total number of occurrences of consecutive nonconformities was smaller and smaller. The largest dispersion of the number of nonconformities in all the examined months was noted for nonconformity with the symbol N_2 (R = 234).

Table 2

Descriptive statistics for the dataset of the number of nonconformities occurrences over the period under study

Designation	**Descriptive statistics**									
	Σ	*Min*	*Max*	*R*	*Me*	Q_1	Q_2	$\bar{x}$	*s*	V_s
N_1	8044	580	793	213	680	620	713	670.33	64.77	9.66
N_2	5971	360	594	234	513	420	576	497.58	80.25	16.13
N_3	4548	265	432	167	400	353	414	379.00	49.62	13.09
N_4	3588	198	356	158	313	280	325	299.00	43.49	14.54
N_5	2998	156	290	134	263	223	288	249.83	44.68	17.88
N_6	2067	121	220	99	171	146	201	172.25	33.70	19.56
N_7	1774	110	195	85	142	127	172	147.83	26.73	18.08
N_8	1393	98	175	77	115	104	120	116.08	20.33	17.51
N_9	1222	82	118	36	102	97	110	101.83	10.92	10.72
N_{10}	922	35	100	65	77	66	95	76.83	19.28	25.09
N_{11}	579	21	76	55	50	29	67	48.25	20.36	42.19
N_{12}	286	14	49	35	21	16	28	23.83	10.26	43.04
N_{13}	177	9	20	11	15	12	18	14.75	3.55	24.04
N_{14}	126	4	16	12	10	9	12	10.50	3.15	29.98

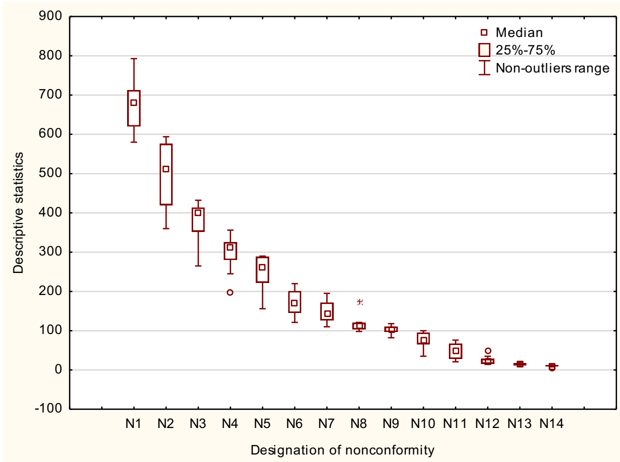


Fig. 1 Box-whisker plot for the analysis of the distribution of the number of individual nonconformities in the cross-section of the studied months

The outliers and the extreme values for the three nonconformities with the symbols N_4, N_8, and N_{12} appearing in the box-whisker charts were noteworthy. This means that the number of occurrences of these nonconformities in a given month was either much lower (N_4) or much higher (N_8, N_{12}) than the remaining instances of nonconformities. In the case of nonconformity with the symbol N_8 in September, as many as 175 cases of this nonconformity were detected, which in this case was an extreme value, i.e. significantly different from the other values of the occurrence of nonconformities.

The comparison of the mean value and standard deviation for the value of the number of occurrences of individual nonconformities in all months was presented in Fig. 2.

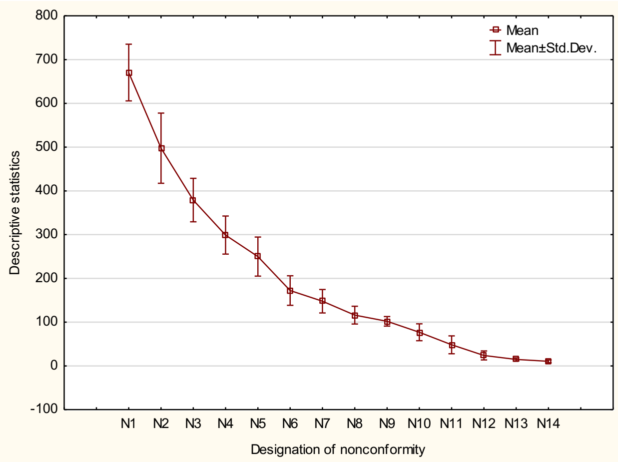


Fig. 2 Mean ± Std.Dev. plot for the analysis of the distribution of the number of nonconformities in the all analysed months

The variability of the number of nonconformity occurrences around the average value of occurrences (s) in the studied months was the largest for nonconformity with the N_2 symbol, i.e. damage to vertical edges, and the smallest for nonconformities with the symbols N_{13} and N_{14} (incompatible size: wide and high). The relative variability of the number of nonconformities (V_s) was greatest for the N_{11} and N_{12} (high grindability and incompatible size: length) nonconformities.

Single measurement and moving range control charts were built to evaluate the behaviour of the number of all nonconformities over time. The constructed control charts showed the lack of stability in the number of non-compliance occurrences in the studied period for only one nonconformity, with symbol N_8 (stain, soil water permanent) (Fig. 3). The number of occurrences of this nonconformity in September was much higher than in the remaining months. The behaviour of the number of occurrences of this nonconformity should be considered unstable and, at the same time, unpredictable in time. The cause of such a large number of occurrences of this particular nonconformity this month should be found and classified (special, random, other). Knowledge about this specific case of nonconformity can be used by managers to improve the process. The control chart also showed that in the following months the value of the nonconformity number returned to the stability limits set by the control limits and did not deviate from the average value anymore.

The results of the correlation analysis with the Pearson correlation coefficient examining the relationship between pairs of nonconformities from the point of view of the number of occurrences of these nonconformities in the studied months were presented in the correlation matrix (Table 3).

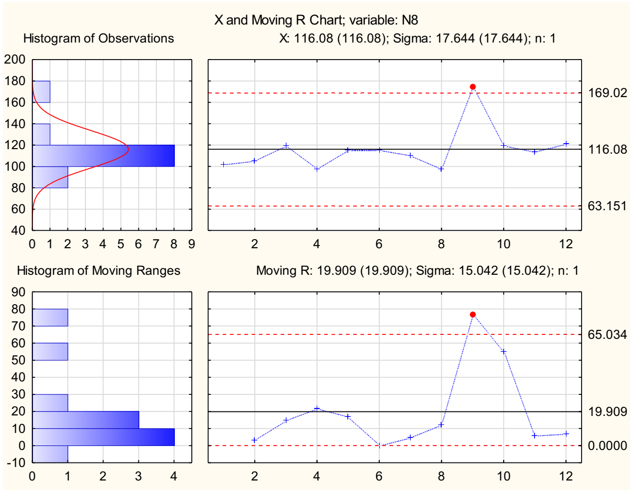


Fig. 3 Control chart for single measurements (X) and moving range (MR) to assess the stability of the number of N_8 nonconformity in the studied months

Table 3

Correlation matrix for the analysis of correlation relationships between the numbers of occurrences of particular types of nonconformities in the examined period

Variable	Correlation coefficients marked bold are significant with p < 0.05													
	N1	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**N10**	**N11**	**N12**	**N13**	**N14**
N1	1.00													
N2	0.14	1.00												
N3	0.17	**0.85**	1.00											
N4	0.39	**0.77**	**0.86**	1.00										
N5	0.22	0.50	**0.75**	**0.70**	1.00									
N6	0.06	0.08	0.40	0.55	**0.64**	1.00								
N7	0.02	0.06	0.28	0.39	0.55	**0.87**	1.00							
N8	-0.32	0.25	0.17	0.16	0.31	0.50	**0.68**	1.00						
N9	-0.23	-0.36	-0.32	-0.46	-0.10	0.12	0.23	0.33	1.00					
N10	0.02	-0.22	0.04	-0.13	-0.01	0.04	-0.00	-0.37	0.51	1.00				
N11	-0.25	-0.13	0.11	-0.23	0.08	0.03	-0.02	-0.07	**0.70**	**0.79**	1.00			
N12	-0.49	-0.28	0.09	-0.23	0.09	0.21	0.04	-0.03	0.33	0.52	**0.71**	1.00		
N13	-0.44	-0.44	-0.16	-0.42	-0.03	0.14	-0.02	0.00	**0.71**	**0.60**	**0.86**	**0.84**	1.00	
N14	-0.14	-0.18	0.16	-0.06	0.21	0.37	0.08	0.07	0.43	0.31	**0.64**	**0.76**	**0.80**	1.00

Statistically significant (at the significance level p = 0.05) correlation relationships between as many as 15 pairs of nonconformities were demonstrated due to the correlation of the number of occurrences of these nonconformities. The strongest correlation in the number of nonconformities occurred between the nonconformities N_6 and N_7, i.e. cracks, dents, and damage to the side corners (r = 0.87). This dependence can be explained by the fact that both nonconformities have common causes because their occurrence is related to inadequate transport, improper storage, and short vibropressing time. There was also a strong correlation of the occurrence of the paving stones' dimensional nonconformities, i.e. length, width, and height, which may be caused by inaccurate drawing and operator errors.
The summary of basic descriptive statistics for the number of nonconformities occurrences by consecutive months is presented in Table 4.

Table 4
Descriptive statistics for the dataset of the number of occurrences of nonconformities over the period under study

Designat.	Descriptive statistics									
	Σ	*Min*	*Max*	*R*	*Me*	Q_1	Q_2	$\bar{x}$	*s*	V_s
1	2759	11	793	782	111.0	32	299	197.07	221.83	112.56
2	2129	9	580	571	107.5	28	198	152.07	159.05	104.59
3	2849	10	742	732	149.0	56	280	203.50	200.49	98.52
4	2882	4	680	676	116.5	29	330	205.86	221.04	107.37
5	2878	12	690	678	121.5	69	280	205.57	213.30	103.76
6	2975	16	620	604	140.0	65	315	212.50	190.39	89.60
7	2873	12	710	698	144.0	43	315	205.21	199.77	97.35
8	2884	8	715	707	116.5	28	356	206.00	224.71	109.08
9	3036	9	624	615	185.0	21	340	216.86	211.27	97.42
10	2989	10	680	670	138.0	57	320	213.50	205.32	96.17
11	2904	15	620	605	119.5	75	310	207.43	195.84	94.41
12	2537	10	590	580	135.0	76	245	181.21	163.64	90.30

Fig. 4 shows the developed box-whisker plot showing the structure of the number of nonconformities in individual months of the year.

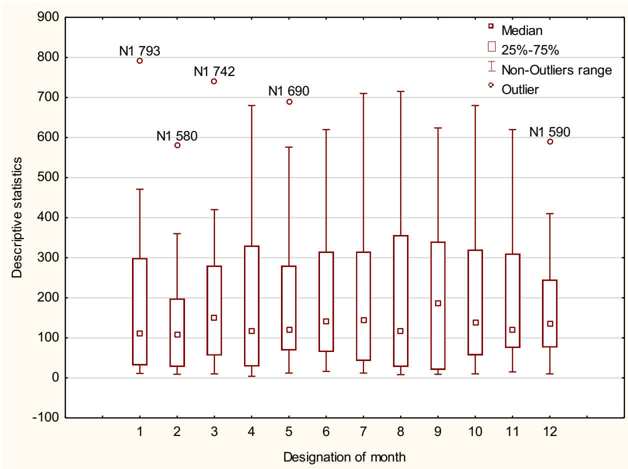


Fig. 4 Box-whisker plot for the analysis of the distribution of the number of nonconformities in terms of the studied months

Fig. 4 showed that in the months from January to March, also in May and December, the nonconformity with a much greater number of occurrences was the nonconformity marked as N_1 (side surface defects). August was the month with the largest range in terms of the number of detected nonconformities.
The plot of the mean and standard deviation for the comparative analysis of the mean value of the number of nonconformities and their variability around the mean value was presented in Fig. 5.

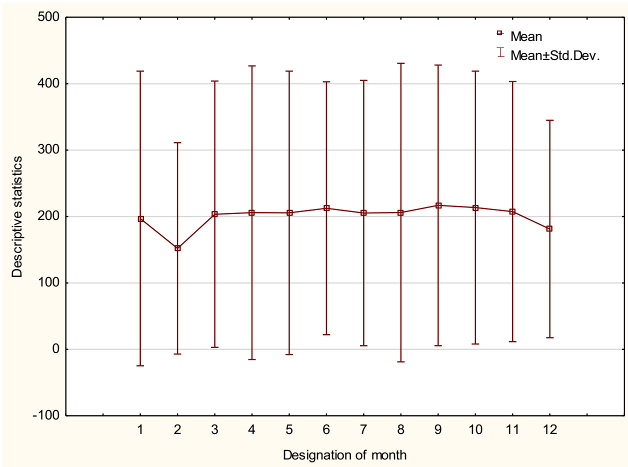


Fig. 5 Mean ± Std.Dev. plot for the analysis of the distribution of the number of nonconformities in terms of the studied months

The highest average value of the number of nonconformities was recorded in September ($X_{av.}$= 216.86). The month with the highest variability in the number of nonconformities around the mean value (s) was August (s = 224.71). The relatively highest variability in the number of nonconformities was recorded in January (V_s = 224.71).
The Chernoff' faces pictorial chart for the analysis of the relationship between the number of occurrences of particular types of nonconformities in the consecutive examined months was presented in Fig. 6.

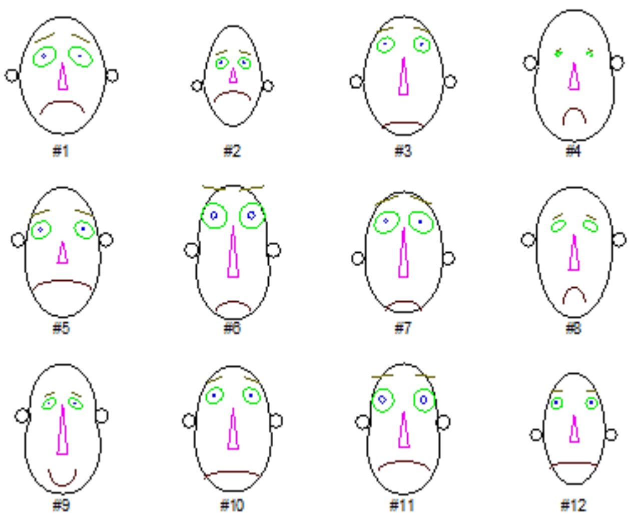


Fig. 6 The Chernoff faces indicating the relationship between the number of occurrences of particular types of nonconformities in the consecutive examined months

Fig. 6 showed that September (the #9[th] month) was unlike any other month. It is represented by a face with a completely different facial expression than the others. This face is optimistic and satisfied; it results from the fact that the number of nonconforming products corresponding to N_8 was the highest this month. The fact that the face smiles does not mean that it is good, it only means that for a given month the variable has large values – and "a lot" does not mean "good" in this case (because there were the 'nonconformities', something unfavourable). On the other hand, the month of February is represented by the relatively smallest face, because the smallest number of nonconformities, from N_1 to N_7, was identified.
The summary of statistical parameters for the entire set of non-compliance data was presented in Table 5.

Table 5
Descriptive statistics for the dataset of the number of occurrences of nonconformities over the period under investigation

Descriptive statistics									
Σ	*Min*	*Max*	*R*	*Me*	Q_1	Q_2	$\overline{x}$	*s*	V_s
33695	4	793	789	120.5	46	304.5	200.57	195.58	97.52

Over a total of 12 months, there were 33,695 cases of nonconformities paving stones. The average number of identified nonconformities was 200 ± 195. The relative variability in the number of nonconformities was very high.
The control chart of single measurements (*X*) and moving range (*MR*) for the stability analysis of the total number of nonconformities in the terms of the following months is presented in Fig. 7.

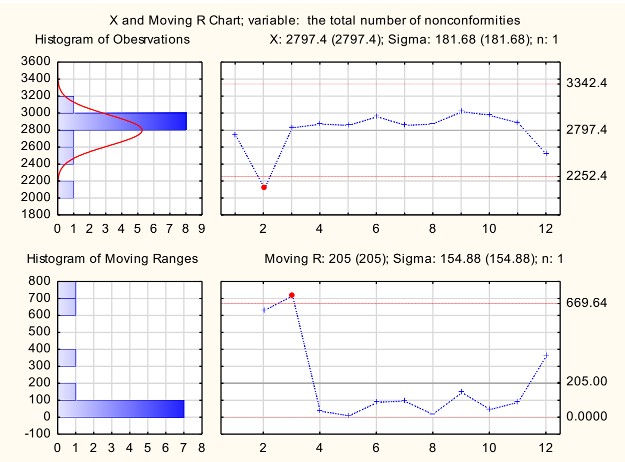


Fig. 7 Single measurement (X) and moving range (MR) control chart to assess the stability of the number of occurrences of all nonconformities in terms of the studied months

According to the control chart, the month of February was the month when the number of nonconformities in the paving stone production process was "disrupted". This month the number of nonconformities was much smaller than in the other months. There is no clear trend in the number of generated nonconformities in the analysed period. The last 3 months show a decreasing trend in the number of nonconformities and in particular the last month, which may, however, be related to the fact that in December the scale of production in the examined plant was clearly lower than in the remaining months of the year, hence the smaller number of recorded nonconformities.
The Pareto-Lorenz diagram for the overall presentation of the number of incidents of nonconformities in the examined period is presented in Fig. 8.

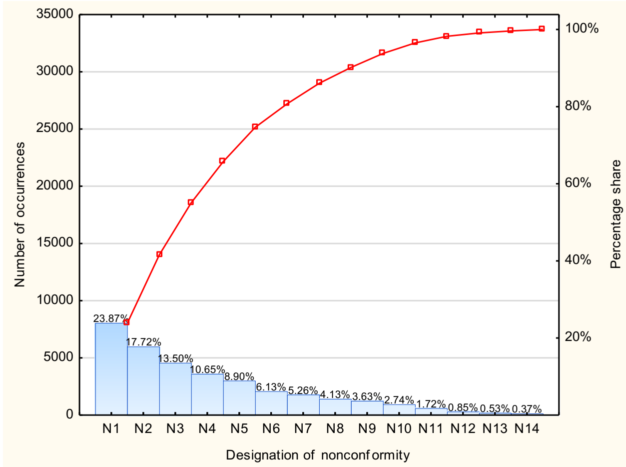
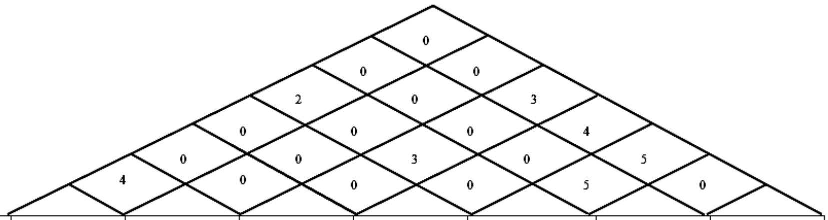


Fig. 8 Pareto-Lorenz diagram for the analysis of the share of incidents of nonconformities in the period of the examined 12 months

The analysis of the Pareto-Lorenz diagram shows that the critical nonconformity in terms of the number of occurrences was the nonconformity denoted as N_1, i.e. damage to the side surfaces. 3 nonconformities from 14 (21.43%), i.e. nonconformities with the symbol N_1, N_2 and N_3, generated 55.09% of quality problems in the production of Behaton-type paving stones.
In order to show the logical connections between the groups of factors influencing the problem of a high percentage of shortages of paving stones, a matrix diagram was prepared (Fig. 9).
After analysing all the relationships, it appears that the most important factor causing a large percentage of nonconformities was the time of shaking/vibrating the concrete, which is in a strong relationship with the technical condition of the machines. Another very important factor was the inadequate composition of concrete, caused by contamination of the components and poor storage conditions. Less important factors that should not be underestimated, however, were the conditions of storage and the contamination of concrete, which are related to each other.



	Technical condition of machines	Kneading/ vibrating time	Inadequate concrete composition	Concrete setting conditions	Ingredient contamination	Transport conditions	Storage conditions
Low product strength	3	5	5	4	3	0	2
Scratches and cracks	2	4	4	2	2	3	3
Surface damage	3	4	3	3	1	5	5
Discoloration	2	3	4	2	5	0	4
Stains and dirt	2	0	0	0	5	4	4
Patchy color	2	4	3	0	3	0	0
Cracks	4	5	5	4	2	5	4
Sum	18	25	24	15	21	17	22

Fig. 9 A matrix diagram for the analysis of the strength of the influence of various factors on the occurrence of nonconformities

The developed Ishikawa diagram for the identification of potential nonconformities of a large percentage of paving stone shortages is shown in Fig. 10.

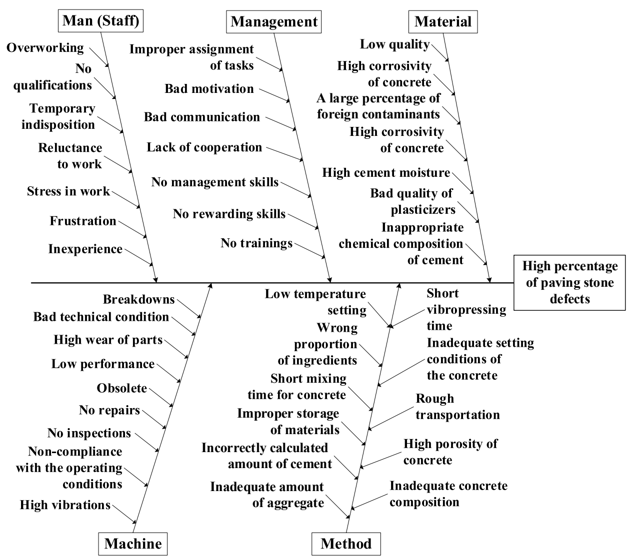


Fig. 10 Ishikawa diagram for identifying potential causes of high percentages of paving stones shortage

The most important reason for the large shortage of paving stones was the lack of efficient maintenance, which led to rapid wear of the machines, as well as non-compliance with the procedures for the production of vibropressed elements, i.e.: improperly selected time of concrete kneading, vibration, and maturation of finished cubes, led to their low strength, high porosity and, as a result, damage and defects. The area with the greatest impact on a large percentage of shortages of paving stones were machines, with particular emphasis on concrete block presses and concrete mixers, where the most common defects in the production process occurred, i.e. wear of bearings, telescopes, rubber cushions, which is caused by the lack of efficient maintenance, and long machine cycles. Low expenditures on the purchase of new machines resulted in the occurrence of a large number of nonconformities, which resulted in the rapid aging of the machine park and, as a result, led to frequent repairs. The elements that had a negative impact on the production also include the quality of the purchased materials (material & method), the lack of workers' training (man & management), and the lack of adequate motivation (man & management).

Considering the above circumstances, it can be concluded that in order to reduce the occurrence of shortages in the paving stone production process, attention should be paid to the following reasons, which in a particular way affect their occurrence:

- Human causes:
  - ✓ improve work discipline as well as the correct preparation of materials for production,
  - ✓ adjust the employee to the entrusted work,
  - ✓ adequately motivate the production staff,
  - ✓ pay attention to the level of training of future production employees,
  - ✓ introduce job-specific checks on personnel.
- Technical reasons:
  - ✓ check the technical condition of machines and carry out appropriate repairs,
  - ✓ carry out frequent inspections and maintenance of equipment used in the production of paving stones,
  - ✓ replace the old machinery park with a new one.
- Technological reasons:
  - ✓ apply a more efficient manufacturing process,
  - ✓ organize a properly secured place for storing materials,
  - ✓ replace the supplier of concrete production materials, which will eliminate some defects,
  - ✓ make purchases based on quality, not price.
- Organizational reasons:
  - ✓ improve work organization,
  - ✓ improve the controls of production processes and employee controls,
  - ✓ optimize the production process,

✓ define the purpose and scope of employees' activities,
✓ increase financial resources for the purchase of new machinery and equipment.

CONCLUSION

The aim of the study was a multidimensional analysis of the nonconformities structure of Behaton paving stones in order to define activities aimed at improving the quality of the production process. The results of multivariate statistical analysis supported by SPC tools and quality tools for the analysis of paving stone nonconformities showed various disturbing signals about the quality level of the tested product over the time period studied. The proof of this was the calculated values of statistical measures, the behaviour of the number of nonconformities in the box-whisker charts, the charts of individual value cards, and the moving range. It also indicated that some nonconformities were related to each other, which can be used for process improvement purposes.

As a result of the statistical analysis of the nonconformity structure of Behaton-type paving stones, it was found that in the studied period of 12 months:

– most quality problems related to nonconformity with the N_1 symbol (side surface defects), the least - nonconformity with the N_{14} symbol (incompatible size: high),
– three nonconformities with the symbol N_1 (side surface defects), N_2 (vertical edge defects) and N_3 (scratches and cracks) generated the majority (55%) of quality problems,
– the largest relative variability of the number of nonconformities was related to the symbol N_{12} (incompatible size: length), the smallest - to the symbol N_1 (side surface defects),
– the behaviour of the number of occurrences of only one nonconformity with the symbol N_8 (stain, soil water permanent) should be considered unstable and unpredictable in time, the special cause of this condition should be identified,
– the strongest positive correlation in terms of the number of nonconformities occurred between nonconformities with the symbol N_6 (cracks and dips) and N_7 (damage to the side corners), which was a consequence of common causes of these nonconformities in the production process,
– nonconformity, which occurred most frequently in all the analysed months and generated significantly higher values than in other cases of nonconformities in the case of 5 different months, was the side surface defects with the symbol N_1,
– the highest average number of nonconformity occurred in September, while the month with the greatest variation in the number of nonconformity around the average value was August, with the relatively highest variation in the number of nonconformity recorded in January,
– it was indicated that the months of February and September were dissimilar to other months in terms of the number of occurrences of nonconformities,
– the relative variability in the number of nonconformities should be considered very high,
– the assessment of the stability of the total number of nonconformities indicated the instability of this number due to an insufficient number of nonconformities in February, which should be treated as a favourable situation,
– the most important factor causing a high percentage of nonconformities was the time of shaking/vibrating concrete, which was in a strong relationship with the technical condition of the machines,
– the most important reason for the high percentage of paving stones was the lack of efficient maintenance, while the most important area of generating nonconformities was the machine (concrete mixers),
– in order to reduce the nonconformities of the paving stones, a number of remedial measures should be implemented, aimed in particular at the area of the machine, man, and method of work.

In order to reduce the occurrence of nonconformities in the paving stone production process, the managers of the examined company should pay attention to the critical problem factors revealed by statistical analyses and analyses using quality tools and take effective corrective actions. The downward trend in the number of nonconformities in the following months of the new year will be proof of the effectiveness of such actions. An additional, recommended FMEA analysis will allow assessing the risk associated with each nonconformity and allow proposing corrective and preventive actions aimed at reducing this risk to an acceptable level for the plant. Lean [40] and TPM [41] tools should also be used to reduce waste on production and increase the efficiency of using production equipment in the studied company. In addition to basic quality management tools [42], ISO 9000, the range of quality management system in studied company must be supplemented by the implementation of process management approaches, the Six Sigma method and also Kaizen philosophy. The future implementation of all the above-mentioned quality management practices [43, 44], could improve the quality of production, and process performance in the studied company, as well as reduce the number of claims and costs for nonconformity products. The success of implementing quality management practices depends on the personality of the managers of the studied company, their personal abilities and charisma, so their potential and abilities in this area should be assessed [45] before entrusting them with related tasks. The manager should be able to lead the subordinate group well and encourage them to work effectively, which should translate into a good result of the team's and the company's work [45].

The limitation of the research results presented in the article is the lack of determination whether the proposed corrective actions have brought the intended effects in the form of reducing the number of nonconformities of paving stones. Further research in this area will therefore be related to the assessment of the effectiveness of the corrective actions taken by determining, by performing the Neumann trend test [46], whether these actions brought a significant effect in the form of a statistically significant decreasing trend in the number of nonconformities cases in the subsequent months of the new year.

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