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ASSESSMENT OF WHETHER MARINE POWER PLANT STEAM SYSTEM FAILURES BELONG TO ONE GENERAL POPULATION

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Abstract

In the paper a number of various types of vessels' power plant steam system failures have been analyzed with regard to the general population they come from. For the purpose of the analysis the Kruskal – Wallis rank sum test and Kruskal – Wallis ANOVA rank test from the statistical packet STATISTICA 8.0 have been used. The analysis was based on the observations of the failure of marine power plants steam systems elements. Failures to the marine power plant systems of 10 ships owned by the Polish Steamship Company of Szczecin was the subject of a statistical data analysis. All the ships differed in respect to their place and time of construction as well as their technical parameters. The data on marine power plants failures was collected in similar conditions, that is, they were supplied by an engine crew member working in the marine power plant. The data on the failures of particular marine power plant systems was obtained accordingly to the test schedule [N, W, T], which means that N renewable objects were the subject of the test within the time T. Since the recovery time of the damaged system appeared negligibly short, when compared to the time of the test, it was assumed that consecutive recoveries overlap the failure moments. The statistical analysis dealt with moments $t_1 \le t_2 \le ... \le t_n$ *of the particular systems' consecutive failures and the length of time intervals* τ_n *between the objects' consecutive failures.*

Keywords: *marine power plant, steam system, failures, the Kruskal-Wallis rank test*

1. Introduction

In failure analysis of complex technical systems, especially when searching for failure distributions, it needs to be determined whether collected statistical data on failures come from the same general population. It needs to be specified, whether they may be analyzed as a set of data characterized by common statistical features. In the paper it has been presented on the basis of marine power plant steam system failures.

The statistical analysis of the data on selected marine power plant steam system failures has been done for the following ships, which were assigned symbols for the ease of description: S1 – m/s "ZIEMIA OLSZTYŃSKA", S2 – m/s "ZIEMIA SUWALSKA", S3 – m/s "HUTA ZGODA", S4 – m/s "GENERAŁ BEM", S5 – m/s "SOLIDARNOŚĆ", S6 – m/s "ZAGŁĘBIE MIEDZIOWE", S7 – m/s "KOPALNIA RYDUŁTOWY", S8 – m/s "OBROŃCY POCZTY", S9 – m/s "MACIEJ RATAJ", S10 – m/s "UNIWERSYTET GDAŃSKI".

The data on power plant failures was collected in similar conditions, that is, supplied by an engine crew member working in the power plant [5, 6].

All the ships differ in respect to their place and time of construction as well as their technical parameters.

Information on failures was collected during an average voyage lasting for up to six months. For the statistical analysis the time accepted is 180 days, with one day as the time unit defining the moments of failures.

The data on failures deals with six systems: lubricating system – IOS, sea water cooling system – IWM, fresh water cooling system – IWS, fuel system – IPal, compressed air system – ISP and steam system – IPar.

The procedure of the statistical analysis refers to individual power plant systems as research objects in spite of the fact that each of them is actually a system combined of many components of complex reliability structure. Causes of the individual system failures were not the subject of consideration. For reliability analysis of complex technical systems, which undoubtedly power plant systems belong to, a number of various methods of the system reliability assessment have been applied, e.g. network [1, 3, 4], various logarithms [2, 7] or a combination of other methods [8, 9, 10].

2. Data on failures

Data on failures of the individual power plant systems was obtained in compliance with the research schedule [*N, W, T*], which means that *N* renewable objects were the subject of the research during the time *T*. Since the time of renewal of the damaged systems turned out negligibly short, when compared to the time of research, an assumption was made that the consecutive moments of renewal overlap with the moments of failures.

Moments of the consecutive failures $t_1 \leq t_2 \leq \ldots \leq t_n$ and the lengths of time between consecutive failures τ_n of the objects in question became the subject of the statistical analysis.

The following assumptions were made:

1) for vessels S1 – S5 the time is measured from the moment of the first failure repair,
2) for vessels S6 – S10 the lengths of time period τ_n between the consecutive failures do not include the time between the beginning of the voyage and the first failure,
3) time period between the last failure and the end of the observation after 180 days have been taken into consideration.

Table 1 shows cumulative number of failures of individual systems on all ships. The next tables contain failure moments and lengths of time between consecutive failures of individual systems for all ten ships.

Table 1. Cumulative number of failures of individual power plant systems on all surveyed ships

Name of the system	Cumulative number of failures										
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Sum
Lubricating system – IOS	3	1	5	6	2	3	21	8	8	9	66
Sea water system – IWM	7	3	4	4	2	11	5	8	8	5	57
Fresh water system – IWS	6	2	6	3	2	7	8	9	5	7	55
Fuel system – IPal	8	12	5	12	6	19	23	17	7	12	121
Compressed air system – ISP	2	1	2	2	2	5	5	8	3	6	36
Steam system– IPar	4	6	3	2	3	10	4	9	3	6	50
Total	30	25	25	29	17	55	66	59	34	45	385

In tables 2 and 3 data on failure of the steam system – IPar, the subject of the analysis, has been presented.

Table 2. Consecutive failure moments of the steam system – IPar

Number of failure	Moments of consecutive failures (days)									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	19	8	76	53	11	3	14	10	37	8
2	52	19	114	110	27	13	27	17	109	34
3	99	25	161		100	21	71	28	149	66
4	123	50				47	91	37		80
5		89				51		45		106
6		93				65		72		122
7						89		111		
8						92		119		
9						119		128		
10						155				

Table 3. Time between consecutive failures of the steam system – IPar

L.p.	Time between consecutive failures (days)									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	19	8	76	53	11	10	13	7	72	25
2	33	11	38	57	16	8	44	11	40	33
3	47	6	47	70	73	26	20	9	31	14
4	24	25	19		80	4	89	8		25
5	57	39				14		27		16
6		4				24		39		58
7		87				3		8		
8						27		9		
9						36		52		
10						25				

3. Assessment of whether steam system failure moments and periods of time between failures come from the same population

Data on marine steam system failures come from different ships of various technical parameters [5, 6]. Thus, it is necessary to verify the hypothesis stating that they come from one population, in other words, that they may be treated as a realization of the same random sample. Only such verification allows for determining general reliability characteristics of particular systems due to the collected statistical data.

The hypothesis was verified by the Kruskal – Wallis rank sum test.

In the test it is assumed that there are k general populations of data with optional distributions and continuous distribution functions $F_1(x)$, $F_2(x)$,..., $F_k(x)$. Out of each population n_i (i=1,2,...,k) random sample elements were independently drawn. Since steam system failure data is not numerous, it is essential that the test does not require any specific sample size.

The verification of the hypothesis H_o: $F_1(x) = F_2(x) =...= F_k(x)$ is presented below.

For that purpose all sample values are arranged in ascending order and assigned ranks. In case of a repeated value the ranks are assigned by averaging their rank positions they would be given if they were not identical. Next the rank sum T_i (i=1,2,...,k) of each sample is calculated separately.

Statistic

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{T_i^2}{n_i} - 3(n+1)\text{, where } n = n_1 + n_2 + ... + n_k\text{,} \tag{1}$$

assuming that the hypothesis H_0 is true, has asymptotic distribution χ^2 with k-1 degree of freedom.

The critical region in the test is built on the right side, which means that the hypothesis H_o is rejected when the statistic value $H \geq \chi^2_{1-\alpha}$, where $\chi^2_{1-\alpha}$ is the quantile of the distribution χ^2 of k-1 degrees of freedom and accepted significance level α.

Making a decision about rejection of H_0 hypothesis or lack of bases for its rejection is also facilitated with knowledge about the test *significance level* $\hat{\alpha}$ for the statistic value $H_{n,}$, obtained from:

$$P\left(\chi^2_{\hat{\alpha}} \geq H_n\right) = \hat{\alpha} \qquad (2)$$

If $\alpha > \hat{\alpha}$, the hypothesis H_0 is rejected, otherwise there is no basis for its rejection.

The test was performed for both t_n moments of consecutive failures and τ_n periods of time between consecutive failures of a given system.

In all tests the accepted significance level was α=0,05.

When verifying the hypothesis H_0: $F_1(x) = F_2(x) = ... = F_{10}(x)$ stating that the consecutive failure moments' t_n distribution of all ships steam systems (IPar) was identical, the data in table 2 was assigned ranks and in table 4 the rank sum T_i and the summands $\frac{T_i^2}{n_i}$ of the sum from formula (1) separately for each of the vessels were calculated.

Table 4. Computation of ranks of the steam system (IPar) consecutive failure moments

Number of failure	Ranks of consecutive failure moments of steam system – IPar									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	9,5	2,5	29	24	5	1	7	4	17,5	2,5
2	23	9,5	42	40	13,5	6	13,5	8	39	16
3	36	12	50		37	11	27	15	48	26
4	46	21				20	33	17,5		30
5		31,5				22		19		38
6		35				25		28		45
7						31,5		41		
8						34		43,5		
9						43,5		47		
10						49				
Rank sum T_i	114,5	111,5	121,0	64,0	55,5	243,0	80,5	223,0	104,5	157,5
T_i^2	13110,3	12432,3	14641,0	4096,0	3080,25	59049,0	6480,25	49729,0	10920,3	24806,3
$\frac{T_i^2}{n_i}$	3277,57	2072,05	4880,33	2048,0	1026,75	5904,9	1620,06	5525,44	3640,1	4134,38

Due to $n_1 = 4, n_2 = 6, n_3 = 3, n_4 = 2, n_5 = 3, n_6 = 10, n_7 = 4, n_8 = 9, n_9 = 3, n_{10} = 6$, so $n = \sum_{k=1}^{10} n_k = 50$.

Thus the statistical value $H = \frac{12}{50 \cdot 51} \cdot 34129{,}6 - 3 \cdot 51 = 7{,}6099$. Comparing the statistical value H=7,6099 with the quantile value of the distribution χ^2 of k-1=9 degrees of freedom $\chi^2_{0,95} = 16{,}9258$ ($H < \chi^2_{0,95}$), it is to be concluded that reasons for rejecting the hypothesis H_0 do not exist; the *significance level* $\hat{\alpha}$=0,5739.

Further on the subject of verification was the hypothesis H_0: $G_1(x) = G_2(x) = ... = G_{10}(x)$ that distribution of time $\tau_{n,}$ between consecutive failures of steam system (IPar) on all ships is identical.

Data in table 3 was assigned ranks and in table 5 the rank sum T_i and the summands $\frac{T_i^2}{n_i}$ of the sum from formula (1) separately for each of the vessels were calculated.

Table 5. Computation of ranks of the periods of time between failures of steam system (IPar)

No	Ranks of the periods of time between failures of steam system – IPar									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	21,5	7,5	52	45	14	12	16	5	50	27,5
2	34,5	14	37	46,5	19,5	7,5	41	14	40	34,5
3	42,5	4	42,5	49	51	30	23	10,5	33	17,5
4	24,5	27,5	21,5		53	2,5	55	7,5		27,5
5	46,5	38,5				17,5		31,5		19,5
6		2,5				24,5		38,5		48
7		54				1		7,5		
8						31,5		10,5		
9						36		44		
10						27,5				
Rank sum T_i	169,5	148,0	153,0	140,5	137,5	190,0	135,0	169,0	123,0	174,5
T_i^2	28730,3	21904,0	23409,0	19740,3	18906,3	36100,0	18225,0	28561,0	15129,0	30450,3
$\frac{T_i^2}{n_i}$	5746,06	3129,14	5852,25	6580,1	4726,57	3610,0	4556,25	3173,44	5043,0	5075,05

Due to $n_1 = 5, n_2 = 7, n_3 = 4, n_4 = 3, n_5 = 4, n_6 = 10, n_7 = 4, n_8 = 9, n_9 = 3, n_{10} = 6$, so $n = \sum_{k=1}^{10} n_k = 55$. Thus, the statistical value $H = \frac{12}{55 \cdot 56} \cdot 47491{,}9 - 3 \cdot 56 = 17{,}0334$. Comparing the statistical value H=17,0334 with the quantile value of the distribution χ^2 of k-1=9 degrees of freedom $\chi^2_{0,95} = 16{,}9258$ ($H > \chi^2_{0,95}$), the hypothesis H_0 needs to be rejected; the *significance level* $\hat{\alpha}$=0,0482. So, data about periods of time between failures is steam system of the vessels do not belong to the same general population.

The analysis of the failure data from table 1 leads to the conclusion that the steam system (IPar) failure frequency on ships S6 and S8 turns out significantly higher than on the other vessels. Thus, an assumption is to be made that the data should be divided into two groups of high and low failure frequency.

Further on the subject of verification was the hypothesis H_0: $G_1(x)=G_2(x)=G_3(x)=G_4(x)=G_5(x)=G_7(x)=G_9(x)=G_{10}(x)$ that $\tau_{n,}$ distribution of time between consecutive failures of steam system (IPar) on all ships S1, S2, S3, S4, S5, S7, S9 and S10 is identical.

Data in table 3 was assigned ranks and in table 6 the rank sum T_i and the summands $\frac{T_i^2}{n_i}$ of the sum from formula (1) separately for each of the vessels were calculated.

Table 6. Computation of ranks of the periods of time between failures of steam system (IPar)

No.	Ranks of the periods of time between consecutive failures of steam system – IPar							
	S1	S2	S3	S4	S5	S7	S9	S10
1	10,5	3	33	26	4,5	6	31	15
2	18,5	4,5	20	27,5	8,5	23	22	18,5
3	24,5	2	24,5	30	32	12	17	7
4	13	15	10,5		34	36		15
5	27,5	21						8,5
6		1						29
7		35						
T_i	94,0	81,5	88,0	83,5	79,0	77,0	70,0	93,0
T_i^2	8836,0	6642,25	7744,0	6972,25	6241,0	5929,0	4900,0	8649,0
T_i^2/n_i	1767,2	948,89	1936,0	2324,08	1560,25	1482,25	1633,33	1441,5

Due to $n_1 = 5, n_2 = 7, n_3 = 4, n_4 = 3, n_5 = 4, n_6 = 10, n_7 = 4, n_8 = 9, n_9 = 3, n_{10} = 6$, $n = \sum_{k=1}^{10} n_k - n_6 - n_8 = 36$. Thus, the statistical value $H = \frac{12}{36 \cdot 37} \cdot 13093{,}5 - 3 \cdot 37 = 6{,}9595$. Comparing the statistical value H=6,9595 with the quntile value of the distribution χ^2 of k-1=7 degrees of freedom $\chi^2_{0,95} = 14{,}0738$ ($H < \chi^2_{0,95}$), it is to be concluded that reasons for rejecting the hypothesis H_0 do not exist; the *significance level* $\hat{\alpha}$=0,4331.

Further on the subject of verification was the hypothesis H_0: $G_6(x) = G_8(x)$, that distribution of time between consecutive failures (τ_n) of steam system (IPar) on ships S6 and S8 was identical.

Data on periods of time between failures of steam system on ships S6 and S8 was assigned ranks and in table 7 the rank sum T_i and the summands $\frac{T_i^2}{n_i}$ of the sum from formula (1) separately for each of the vessels were calculated.

Table 7. Computation of ranks of the periods of time between consecutive failures of steam system (IPar)

No	Ranks of the periods of time between consecutive IPar failures of steam system – Ipar	
	S6	S8
1	9	3
2	5	10
3	14	7,5
4	2	5
5	11	15,5
6	12	18
7	1	5
8	15,5	7,5
9	17	19
10	13	
T_i	99,5	90,5
T_i^2	9900,25	8190,25
T_i^2/n_i	990,03	910,03

Because $n_6 = 10, n_8 = 9$, $n = n_6 + n_8 = 19$, so the statistical value $H = \frac{12}{19 \cdot 20} \cdot 1900{,}06 - 3 \cdot 20 = 0{,}0019$. Comparing the statistical value H=0,0019 with the quantile value of the distribution χ^2 of k-1=1 degrees of freedom $\chi^2_{0,95} = 3{,}842$ ($H < \chi^2_{0,95}$), it is to be concluded that reasons for rejecting the hypothesis H_0 do not exist; the *significance level* $\hat{\alpha}$ =0,9652.

Therefore of the above presented the Kruskal – Wallis tests point out that for steam system (IPar) consecutive moments of failures on all 10 ships can be treated as a sample coming from the same general population with periods of time between failures which need to be divided into two groups: the first one including ships S1, S2, S3, S$, S5, S7, S9, S10 of low frequency failure and the second one comprising S6 and S8, ships of steam system high frequency failures.

Next stage of the work was a similar test performed by computer packet *STATISTICA 8.0*.

Available tests to be performed for *n* independent samples are ANOVA rank Kruskal – Wallis and median test from the packet *STATISTICA 8.0*.

The Kruskal – Wallis test is a nonparametric equivalent to one – factor variance analysis. Due to the test it was estimated whether *n* independent sample data come from the same population or from the population of the same median. Individual samples do not need to have identical sample sizes. Median test appears a less accurate version of ANOVA Kruskal – Wallis test, that is, the survey statistic is not built on the basis of raw data or ranks.

In order to analyze marine power plant steam systems there are no bases for rejection of null hypothesis concerning the distribution of consecutive failure moments t_n coming from one general population at the accepted significance level α=0,05, which is confirmed by the results of ANOVA Kruskal – Wallis test shown in fig. 1. Box plots for all distributions have been presented in fig.2.

The Kruskal-Wallis test: H(9, N=50) = 7,611853; p = 0,5737		
Marking of the steam system	N - number of all observations	Rank sum
1	4	114,5000
2	6	111,5000
3	3	121,0000
4	2	64,0000
5	3	55,5000
6	10	243,0000
7	4	80,5000
8	9	223,0000
9	3	104,5000
10	6	157,5000

Fig. 1. Results of Kruskal – Wallis test for the consecutive failure moments t_n of the steam system presented in STATISTICA 8.0 table; N – number of all observations, 9 – number of degrees of freedom of distribution χ^2 of statistic H, H – value of Kruskal – Wallis statistic, p – value

In case of distributions of periods of time t_n between consecutive failures of marine steam system, probability level obtained in the ANOVA Kruskal-Wallis test approximates to 0,05 and equals p=0,0479 (fig. 3). However, from the formal point of view, the null hypothesis that distributions of periods of time t_n between consecutive failures come from one general population on the assumed significance level α=0,05 should be rejected. Therefore, additional median test (fig. 4) accessible in the window *Nonparametric statistics>comparison of a number of independent samples (groups)* from *STATISTICA 8.0* was performed. The median test [13, 14] is the less accurate version of ANOVA Kruskal-Wallis test, that is, the test statistic is not built on the basis of raw data or their ranks – the presented calculations are based on contingency table.

In particular, in each of the samples the *STATISTICA* program computes the number of cases above or below the common median and calculates chi-square statistic value for contingency table results 2 × n samples. According to the null hypothesis (that all samples come from a population with identical medians) it is to be expected that approximately 50% of all cases occur above or (below) the common median. The test appears especially useful in cases where the measuring scale includes artificial limits and a number of cases occur at the scale end. In such a situation the median test turns out to be the only method to be applied for comparing samples.

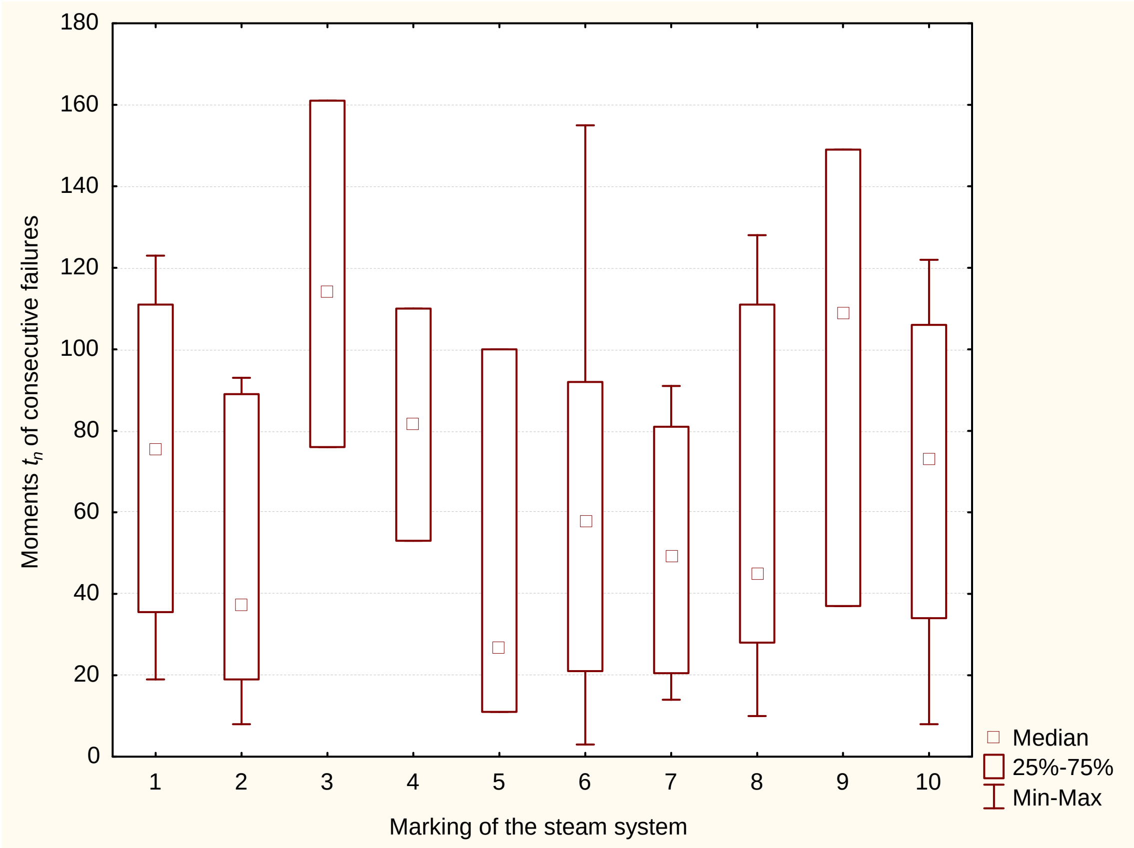

Fig. 2. Box plots for distribution moments t_n of steam system consecutive failures developed due to STATISTICA 8.0

The Kruskal-Wallis test: H(9, N=55) = 17,05462; p = 0,0479		
Marking of the steam system	N - number of all observations	Rank sum
1	5	169,5000
2	7	148,0000
3	4	153,0000
4	3	140,5000
5	4	137,5000
6	10	190,0000
7	4	135,0000
8	9	169,0000
9	3	123,0000
10	6	174,5000

Fig.3. Results of the Kruskal – Wallis test for distributions of periods of time τ_n between consecutive steam system failures presented in STATISTICA 8.0 tables; N – number of all observations, 9 – number of degrees of freedom of asymptotic distribution χ^2 of statistic H, H – statistic value of Kruskal – Wallis test, p – value

	Median test, general median = 25,0000; Independent (grouping) variable: marking of the steam system Chi square = 11,62333; df = 9; p = 0,2354										
	1	2	3	4	5	6	7	8	9	10	Total
<=medians:observed	2,00000	5,0000	1,0000	0,0000	2,00000	7,0000	2,00000	6,0000	0,0000	4,00000	29,0000
expecte	2,63636	3,6909	2,1090	1,5818	2,10909	5,2727	2,10909	4,7454	1,5818	3,16363	
observed-expect	-0,63636	1,3090	-1,1090	-1,5818	-0,10909	1,7272	-0,10909	1,2545	-1,5818	0,83636	
>medians:observed	3,00000	2,0000	3,0000	3,0000	2,00000	3,0000	2,00000	3,0000	3,0000	2,00000	26,0000
expecte	2,36363	3,3090	1,8909	1,4181	1,89090	4,7272	1,89090	4,2545	1,4181	2,83636	
observed-expect	0,63636	-1,3090	1,1090	1,5818	0,10909	-1,7272	0,10909	-1,2545	1,5818	-0,83636	
Total: observed	5,00000	7,0000	4,0000	3,0000	4,00000	10,0000	4,00000	9,0000	3,0000	6,00000	55,0000

Fig.4. Results of median test for the distributions of periods of time τ_n between failures of steam system presented in STATISTICA 8.0 table

On the basis of the median test there are no bases for rejection of the null hypothesis with the distributions of periods of time τ_n between consecutive failures coming from one general population (probability level p=0,2354) with the accepted significance level α=0,05. For that purpose additional multiple (double – sided) comparisons of all sample ranks were performed. The probability values *post - hoc* obtained by means of multiple comparisons and rated values „z" do not prove significant statistical differences among particular pairs of distributions (fig. 5 and 6).

	p-value for multiple (double-sided) comparisons; Independent (grouping) variable: marking of the steam system The Kruskal-Wallis test: H(9, N= 55) = 17,05462; p = 0,0479									
	1 R:33,900	2 R:21,143	3 R:38,250	4 R:46,833	5 R:34,375	6 R:19,000	7 R:33,750	8 R:18,778	9 R:41,000	10 R:29,083
1		1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
2	1,000000		1,000000	0,906151	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
3	1,000000	1,000000		1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000
4	1,000000	0,906151	1,000000		1,000000	0,373978	1,000000	0,387875	1,000000	1,000000
5	1,000000	1,000000	1,000000	1,000000		1,000000	1,000000	1,000000	1,000000	1,000000
6	1,000000	1,000000	1,000000	0,373978	1,000000		1,000000	1,000000	1,000000	1,000000
7	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000		1,000000	1,000000	1,000000
8	1,000000	1,000000	1,000000	0,387875	1,000000	1,000000	1,000000		1,000000	1,000000
9	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000		1,000000
10	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	1,000000	

Fig. 5. View of the table of post – hoc probability values for the comparison of pairs of distributions for periods of time τ_n between consecutive steam system failures and mean ranks value of R distributions for calculations performed in STATISTICA 8.0 program

	Value 'z' for multiple comparisons; Independent (grouping) variable: marking of the steam system The Kruskal-Wallis test: H(9, N= 55) = 17,05462; p = 0,0479									
	1 R:33,900	2 R:21,143	3 R:38,250	4 R:46,833	5 R:34,375	6 R:19,000	7 R:33,750	8 R:18,778	9 R:41,000	10 R:29,083
1		1,359916	0,404761	1,105418	0,044198	1,698013	0,013957	1,692283	0,606840	0,496508
2	1,359916		1,703631	2,323791	1,317735	0,271414	1,255494	0,292935	1,796146	0,890871
3	0,404761	1,703631		0,701476	0,342060	2,031010	0,397231	2,022602	0,224745	0,886405
4	1,105418	2,323791	0,701476		1,018162	2,639183	1,069240	2,626790	0,445941	1,566854
5	0,044198	1,317735	0,342060	1,018162		1,622170	0,055171	1,620101	0,541431	0,511698
6	1,698013	0,271414	2,031010	2,639183	1,622170		1,556228	0,030189	2,086060	1,218807
7	0,013957	1,255494	0,397231	1,069240	0,055171	1,556228		1,555182	0,592509	0,451261
8	1,692283	0,292935	2,022602	2,626790	1,620101	0,030189	1,555182		2,080626	1,220500
9	0,606840	1,796146	0,224745	0,445941	0,541431	2,086060	0,592509	2,080626		1,051926
10	0,496508	0,890871	0,886405	1,566854	0,511698	1,218807	0,451261	1,220500	1,051926	

Fig. 6. View of the table of normal values „z" for comparison of pairs of distributions of periods of time τ_n between consecutive failures of steam system and the value of mean ranks of R distributions for calculations performed in STATISTICA 8.0 program

Box plots of all distributions were presented in fig. 7. The obtained results of nonparametric tests do not explicitly verify the null hypothesis that distributions of periods of time τ_n between consecutive failures come from one general population at the assumed significance level α=0,05.

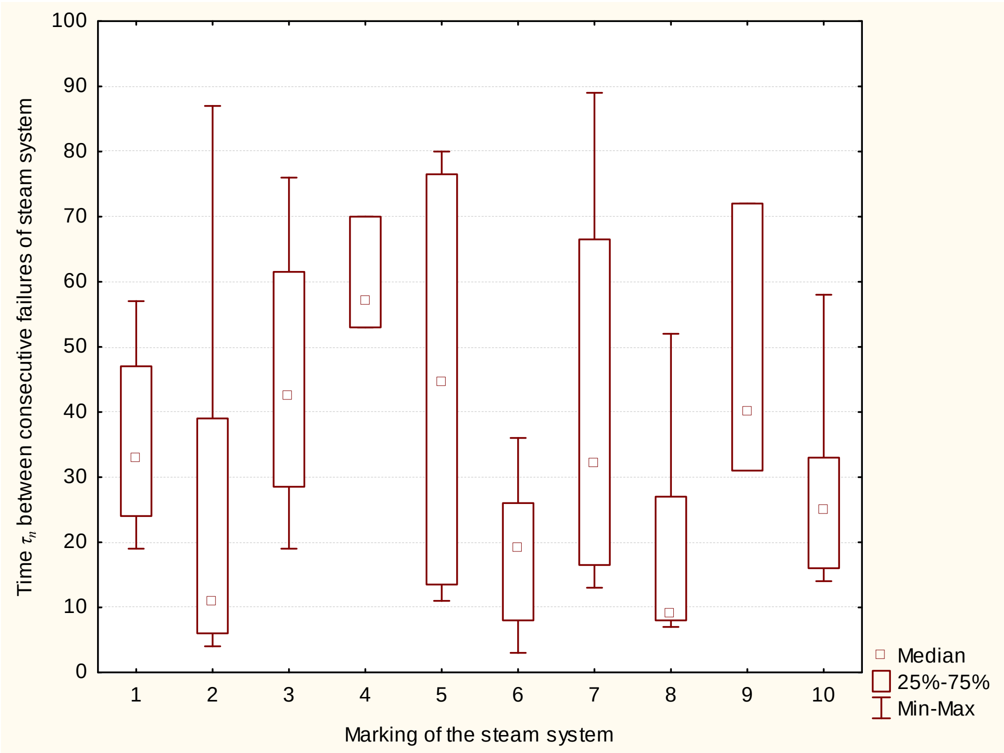

Fig. 7. Box plots of distributions of periods of time τ_n between consecutive steam system failures developed by means of STATISTICA 8.0

The performed multiple comparisons (fig. 5 and 6) do not show which distributions differ statistically from others. Because ANOVA rank Kruskal – Wallis test can be performed by means of *STATISTICA 8.0* program relatively quickly, it was performed several times for distributions of periods of time τ_n between consecutive failures without data from one or two marine steam systems considered. The distributions were selected according to sample sizes, that is, the biggest and smallest sizes, e.g. S4, S3, S9, S6, S8, S4 and S3, S4 and S9, S6 and S8 were considered. Each time the test results did not provide bases for rejection of the null hypothesis that the distributions came from one general population. Thus, it is to be assumed that the null hypothesis stating that all 10 considered distributions of periods of time τ_n between consecutive steam system failures come from one population, is true and the outcome of ANOVA Kruskal – Wallis test (p=0,0479) is the result of too short period of steam system observation.

The disadvantage of nonparametric tests is their smaller potential in reference to parametric tests. The nonparametric test power can be enhanced due to the increase of sample sizes of the considered random variables.

4. Conclusion

Nowadays consecutive stages of statistical inference aided by statistical computing software packages got fairly shortened. Classic stages of statistical inference (with no statistical computing packages) used to run in the following way [13, 14]:

1. data input;
2. formulation of null hypothesis;
3. checkup of the selected test assumptions;
4. calculation of the test value on the basis of the sample results;
5. finding critical values in statistical tables at the fixed significance level;
6. making decision about rejection or acceptance of the null hypothesis at the fixed significance level;
7. interpretation of the obtained results;

The software package application allows for omitting computing stages 4 and 5, yet, it does not perform the job for a researcher at the other statistical interference stages [11, 12].

While verifying hypotheses by means of statistical packages, the notion of probability level p occurs. It is the lowest significance level, often referred to as p – value [13, 14], computed in the computer packages, at which the calculated value of test statistic leads to the rejection of null hypothesis. Following the formulation of the null hypothesis and acceptance of the significance level α, the test is performed and its outcome is the test spreadsheet with the computed probability level p. If $p<\alpha$, at a given significance level a, the null hypothesis is rejected, but when $p>\alpha$, on a given significance level, there is no basis for rejection of the null hypothesis. Actually, the value of α is not usually given, whereas p provides the information on hypothesis verification results [13].

Nonparametric tests are used in cases where the assumptions for parametric tests [13] are not met, e.g. in case of measurable random variables, normal distribution or equal variance of random variables etc. They are also applied in cases of quality data or when they can be ordered only according to specified criteria and in cases of small size groups.

References

[1] Abraham J.A., *An improved method for network probability*. IEEE Transactions on Reliability. Vol. R-28, No. 1, 1979, pp. 58-61.

[2] Aggarwal K.K., Misra K. B., Gupta J.S., *A fast algorithm for reliability evaluation*. IEEE Transactions on Reliability. Vol. R-24, No. 1, 1975, pp. 83-85.

[3] Agraval J.A., Barlow R.E., *A survey on network reliability and domination theory*. Operations Research, Vol. 32, 1984, pp. 478-492.

[4] Ahmad S.H., Jamil A.T.M., *A modified technique for computing network reliability*. IEEE Transactions on Reliability, Vol. R-36, No. 5, 1987, pp. 554-556.

[5] *Analiza statystyczna danych o uszkodzeniach wybranych instalacji siłowni okrętowych*. Raport nr 1997/9 Projektu Badawczego Nr 9T12C07710 pod kierownictwem Zbigniewa Matuszaka: Badanie uszkodzeń i rozkładów uszkodzeń złożonych układów technicznych na przykładzie instalacji siłowni okrętowych. Wyższa Szkoła Morska w Szczecinie, Szczecin 1997, maszynopis.

[6] *Analiza statystyczna danych o uszkodzeniach wybranych instalacji siłowni okrętowych* (cz. II). Raport nr 1998/16 Projektu badawczego Nr 9 T12C 077 10 pod kierownictwem Zbigniewa Matuszaka: Badanie uszkodzeń i rozkładów uszkodzeń złożonych układów technicznych na przykładzie instalacji siłowni okrętowych. Wyższa Szkoła Morska w Szczecinie, Szczecin 1998, maszynopis.

[7] Bailey M.P., Kulkarni V.G., *A recursive algorithm for computing exact reliability measures*. IEEE Transactions on Reliability, Vol. R-35, No. 1, 1986, pp. 40-56.

[8] Dotson W.P., Gobien J.O., *A new analysis technique for probabilistic graphs*. IEEE Transactions on Circuits and Systems, Vol. CAS-26, No. 10, 1979, pp. 855-865.

[9] Fong C.C., Buzacott J.A., *Improved bounds for system-failure probability*. IEEE Transactions on Reliability, Vol. R-36, No. 4, 1987, pp. 454-458.

[10] Heidtmann K. D., *Bounds on reliability of a noncoherent system using its length & width*. IEEE Transactions on Reliability. Vol. R-31, No. 5, 1982, pp. 424-427.

[11] Rausand M., Høyland A., *System Reliability Theory: Models, Statistical Methods and Applications*. Second edition. New Jersey: Wiley, Interscience 2004.

[12] Saleh J. H., Marais K., *Reliability: How much is it worth? Beyond its estimation or prediction, the (net) present value of reliability*. Reliability Engineering and System Safety Vol. 91, 2006, pp. 665–673.

[13] Stanisz A., *Przystępny kurs statystyki. Tom 1: Statystyki podstawowe*. StatSoft, Kraków 2006.

[14] StatSoft – Statistica 8.0, *Podręcznik elektroniczny STATISTICA*.