Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-43956
www.engineeringscience.rs

Journal of Applied Engineering Science
Vol. 21, No. 4, 2023
Original Scientific Paper
Paper number: 21(2023)4, 1147, 1074-1082

DIFFERENCES BETWEEN BRIDGE AND GANTRY CRANES' DOWNTIMES

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Maintenance is especially crucial when it comes to construction machinery due its capacity to avoid or reduce the risk of serious accidents by recognizing probable failures and downtimes in a timely manner. To properly implement maintenance strategy, it is required to identify the existing linkages between downtime and failures that have already occurred first. This paper aims to analyze and compare data on the length of downtime, as well as the causes of downtime hazard levels on different bridge and gantry cranes. In order to ascertain whether there is a dependency between these two types of cranes, a comparison of the failure duration and hazard level between bridge and gantry cranes is done in this paper. In addition, a comparison of nine different types of bridge and gantry cranes were compared using the same comparation categories. After performing descriptive statistics and the Kolmogorov-Smirnov and Shapiro-Wilk normality tests, which revealed that the data did not follow a normal distribution, a comparison was done using the Mann-Whitney U test and the Kruskal-Wallis tests. All tests revealed no statisticaly significant differences in failure duration and hazard level within the tested categories, which opens up the possibility of applying the same risk management strategies and maintenance procedures regarding both examined crane types.

Keywords: cranes, downtimes, differences, statistics, equipment failures

1 INTRODUCTION

The synergistic impact of all elements of the business system, of which maintenance is an important component, is required for the accomplishment of business objectives [1]. The concept of maintaining a specific technical system is the framework within which the maintenance policy is implemented, and it undoubtedly has an impact on all other parts of the company; therefore, when selecting an appropriate maintenance concept, it is necessary to approach the analysis of the interdependence of organizational and technical factors holistically. The maintenance function's potential as a profit producer has only recently been recognized, and the continuous intricacy of technological systems leads to a divide in the creation of maintenance models and the progress of technology in reality [2]. In today's business world, the maintenance role is increasingly becoming a crucial element in an organization's competitiveness. In reality, proper maintenance management is closely linked to efficiency, in order to maximize results and lower total operation costs, to meet ultimate client satisfaction, and lastly, employee well-being and preservation of the environment [3], [4]. Because of the diversity of technical systems that must be maintained, the rise in complexity, costs, and requirements of production and service plans, technical advancement, and increasingly complicated technologies in maintenance processes, maintenance is a function of particular significance today. The growing diversity of technical systems, their complexity, the intensity of production function demands, methods of using technical systems, and evident scientific and technological development all contribute to the complexity of maintenance tasks. According to the structural form, cranes are classified into several groups: tower, bridge, portal, semi-portal, manual cranes, etc., while from the point of view of the implementation of logistics processes the most important types are bridge, flat and ports/portal cranes [5], [6]. But, data regarding cranes downtimes are rarely available.

Accordingly, this paper aims to analyze and compare data on the length of downtime, as well as the causes of downtime on different bridge and gantry cranes. The data were collected in the real working environment of the machines and descriptive statistics were first performed on them, then their normality was tested by Kolmogorov-Smirnov and Shapiro-Wilk tests, and than the mutual comparison of machine types was performed by the Mann-Whitney U test and the Kruskal–Wallis test on independent samples.

2 PREVIOUS RESEARCH

Work in different types of industry is not possible without modern efficient lifting devices and machines [7]. When it comes to cranes, it is clear that, despite ongoing improvements in upkeep and inspection processes, cranes remain devices that pose the greatest risk in mining and building sites [4], [8], [9]. Operating the crane poses a risk not only to the operators, but also to all other employees in site [7], [9]–[12]. In the field of cranes legislation standards ISO 9927-1:2009, ISO 9927-3:2005 and ISO 23814:2009 should be mentioned. Except for material damage, sick leave costs and decreased employee motivation, the consequences of work-related accidents frequently entail injuries at work and/or death outcomes for staff members in the immediate surroundings [13]. Tomakov in [12] add that as the main causes of accidents are characterized as caused by “human factor” - low technological discipline, inadequate employees' qualifications, poor-quality installation and untimely equipment repair. Authors in [14] conducted simulations to develop a model for estimating company risks in the case of different types of crane error. Maintenance has rightfully assumed responsibility for the correct operation of locations where accidents could occur, emphasizing its significance [12], [15]. Researchers in [16] identify as the main accidents causes poor inspection and maintenance of the crane, lack of communication, and workers' negligence, according to the data collected by the questionnaire usage in Malasia, while authors in [13] propose to pay special attention to both to the electrocution, and to the contribution of impacts with the load and the crane (strikes) after accidents analysis. Yu in [17] analyses forensic reports and comes to conclusion that the most frequent accident cases are mobile crane toppling, hoist wire rope breakage and boom/jib collapse of tower crane. Data regarding the cycle times including downtimes are very rarely available and even rarer analyzed. One of rare researches on tower cranes cycles times is done in [18], and notices that shortening of cycle time leads to higher productivity. Another rare research that should be mentioned is done by [19], and there authors use ANN to predict equipment downtime. Evidently, data on downtimes are rarely available and accordingly research on that topic is consequently rare, too. In brief, crane safety research has been confined to trials, simulations, and methodological inquiries. Additionally, although risk-based maintenance techniques and technical diagnostic methods have received increasing attention in recent years [20], and although it known that cranes, as a group of the most widely used materials handling equipment, are responsible for up to one-third of all fatal cases in certain branches of industry, the creation of maintenance models for particular technological systems outside of the nuclear and petrochemical industries is moving too slowly. The key to successful risk management is early planning and aggressive implementation, but data on the condition of cranes, almost as a rule, in industrial companies in Serbia, are not collected, stored or analyzed up-to-date. Conditional maintenance with reliability level control, which involves the collection, processing and analysis of data on the reliability level of system components, in real time, is therefore not possible and is an initial limitation [21], [22]. It evident that any kind on cranes downtimes analysis would be beneficial and this paper aims to investigate similarities or differences between different structural types of cranes in order to increase the efficiency of the maintenance process.

3 METHODOLOGY

In the experimental part of the research, data on unplanned stoppages of cranes were recorded over a period of one year. The operation of cranes with the following characteristics was monitored:

- Double girder bridge crane with capacity of 10 tons and span of 29 meters
- Double girder bridge crane with capacity of 16 tons and span of 27 meters
- Double girder bridge crane with capacity of 20 tons and span of 16.7 meters
- Double girder bridge crane with capacity of 20 tons and span of 22.5 meters
- Double girder bridge crane with capacity of 32 tons and span of 24 meters
- Single girder bridge crane with capacity of 10 tons and span of 22.5 meters
- Single girder bridge crane with capacity of 5 tons and span of 29 meters
- Gantry crane with capacity of 63 tons and span of 18 meters
- River gantry crane 160/50t

In the observed time interval, stoppages of the mentioned cranes were monitored and the causes of stoppages and their duration were recorded. A total of 1091 stoppages were recorded, which are summarized by cause and shown in table 1. The total time spent in unplanned stoppages at the mentioned cranes was 179290 minutes. Each stoppage identified and shown in Table 1, after the conducted research, was evaluated by an expert with a score from 1 to 10, which represents the scale of the level of hazard. Score 10 represents the highest level of hazard and vice versa, score 1 represents the lowest level of hazard.

Table 1. Identified causes of downtime and their structure of frequency of occurrence and duration of downtime in minutes - summary data

Causes of downtime	Frequency of occurence	Sum of downtime duration
Crane limit switch	176	5750
Two step trolley limit switch	165	6015
Hook safety latch	97	3955
Hoisting brake	70	9030
Hoisting rope guide	56	3510
Bridge panel main contactor	53	1655
Shaft bearing	42	27250
Hoisting motor wiring	40	24480
Hoist gear / Tooth breakage	29	15800

Causes of downtime	Frequency of occurence	Sum of downtime duration
Crane overload device/switch	28	3800
Trolley wheels bearing	28	3745
Hoisting drum bearings	28	3350
Sheaves bearings	15	5530
Crane gear	14	8400
Gear shaft	14	8300
Trolley wheels flanges	14	5080
Crane wheels flanges	14	5040
Hoisting rope	14	3360
Hook shaft bearing	14	1680
Bearing shafts of trolley gear	14	1680
Trolley travelling drive	14	1680
Crane travelling brake rectifier	14	1680
Hoist brake rectifier	14	1680
The upper hoisting limit switch	14	1680
Crane wheels bearing	14	1680
Crane drive	14	1680
Trolley travelling brake rectifier	14	1660
Hoisting motor fan	14	830
Fuses of the bridge panes	14	420
Hoisting clamp	12	2860
Crane travelling mechanism frequency inverter	12	1410
Trolley travelling mechanism frequency inverter	12	1380
Storm lock device	2	13000
Hoist frequency inverter	2	240
TOTAL	**1091**	**179290**

4 RESULTS

4.1 Descriptive Statistics

Table 2 shows the results of descriptive statistics for the collected data on the duration of downtime that occurred on the equipment, as well as the estimated Hazard level for each of the causes listed in Table 1. Table 2 contains the sample mean, standard error, median, variance, standard deviation, minimum, maximum and their distribution Skewness and Kurtosis.

Table 2. Descriptive statistics

	Failure Duration	Hazard Level
Mean	164.34	3.25
Standard Error	10.354	0.087
Median	60.00	2.00
Variance	116971.049	8.230
Standard Deviation	342.010	2.869
Minimum	20	1
Maximum	7000	10
Skewness	12.421	1.674
Kurtosis	223.648	1.234

Figures 1 and 2 are histograms that show relationships between failure duration and occurrence frequency and the frequency of hazards at each level.

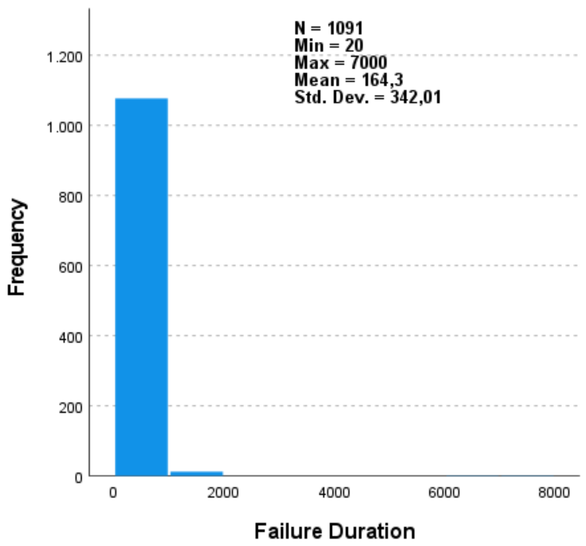

Figure 1. Field information Failure duration

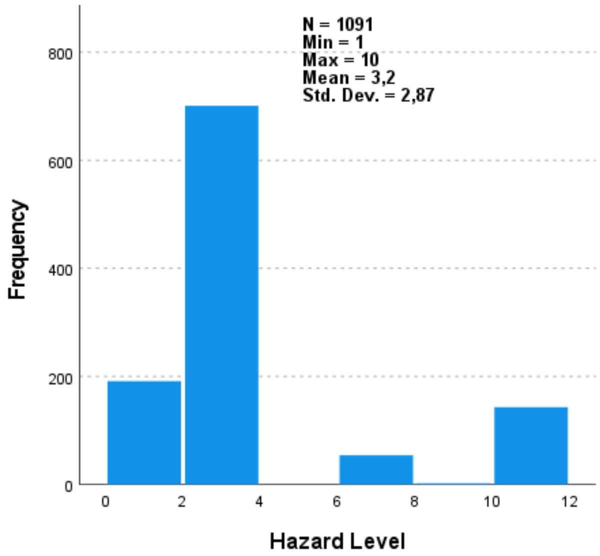

Figure 2. Field information Hazard level

Histogram 3 shows the distribution of collected data in relation to the machine model, and in total there is 1091 entered data.

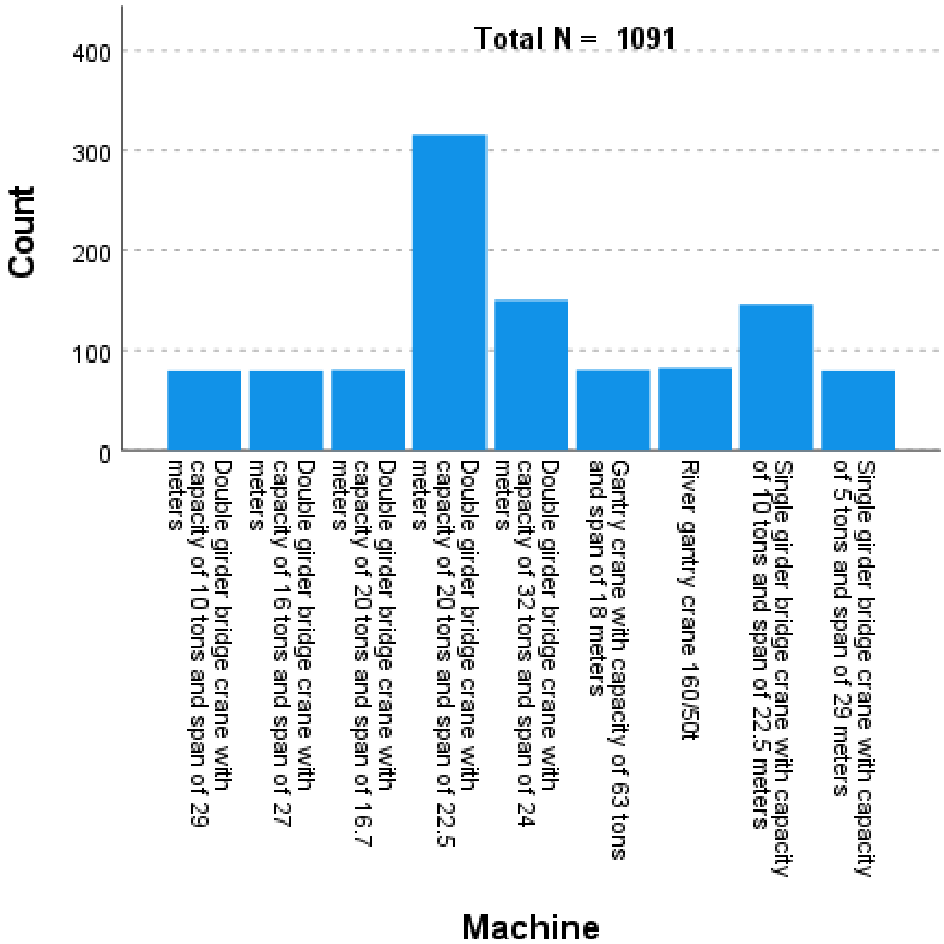

Figure 3. Number of field information about machines

4.2 Normality tests

Sample normality testing was performed using two tests: the Kolmogorov-Smirnov and Shapiro-Wilk tests. The data on the duration of downtime on the machine, as well as the data on the Hazard level, were tested. The results of the tests are given in Table 3, where it can be seen that both samples have 1091 degrees of freedom (df) and p values of 0.00, which indicate that the data do not tend to a normal distribution [23].

Table 3. Kolmogorov-Smirnov and Sharpio-Wilk Tests of Normality

		Failure Duration	Hazard Level
Kolmogorov-Smirnov[a]	Statistics	0.337	0.352
	df	1091	1091
	Sig.	0.000	0.000
Sharpio-Wilk	Statistics	0.336	0.638
	df	1091	1091
	Sig.	0.000	0.000

a. Lilliefors Significance Correction

4.3 Hypothesis Testing

Hypothesis testing was performed in two parts. As testing for normality of the samples showed that the data were not subject to a normal distribution, both tests were performed with non-parametric tests [23]. First, the data between the 2 types of transport machines were compared using the Mann-Whitney U test on the duration of downtime (Table 4), and then on the hazard level (Table 5). The tests are shown graphically in figures 4 and 5. After that, the data between the machines were compared depending on the type of construction, load capacity and span. The test used for this part was Kruskal-Wallis. The sample size on bridge cranes contained 931 records regarding seven different cranes, while on gantry cranes contained 160 records regarding two different cranes. Both the Mann-Whitney U test and the Kruskal–Wallis test not require sample sizes to be the same in examined groups and work appropriately on mutually independent samples [23].

Given that it is necessary to compare two groups of data with a non-parametric test, the following hypotheses were proposed for the first test:

H_0: There is no statisticaly significant difference between data on failure duration between bridge and gantry cranes.

H_1: There is statisticaly significant difference between data on failure duration between bridge and gantry cranes.

and for the second test:

H_0: There is no statisticaly significant difference between data on hazard level of failure between bridge and gantry cranes.

H_1: There is statisticaly significant difference between data on hazard level of failure between bridge and gantry cranes.

Table 4. Mann-Whitney test on Failure Duration

Total N	1091
Mann-Whitney U	77678.500
Wilcoxon W	90881.500
Test Statistic	77678.500
Standard Error	3656.275
Standardized Test Statistic	0.664
Asymptotic Sig.(2-sided test)	0.506

Table 5. Mann-Whitney test on Hazard Level

Total N	1091
Mann-Whitney U	75962.500
Wilcoxon W	89165.500
Test Statistic	75962.500
Standard Error	3437.623
Standardized Test Statistic	0.208
Asymptotic Sig.(2-sided test)	0.836

A summary of the results is given in Table 6, from which it can be seen that the null hypothesis cannot be rejected for any set of data since the significance level is not below 0.05 [23], i.e. it can be concluded that there are no statistically significant differences in the data.

Table 6. Mann-Whitney tests summary

	Null Hypothesis	Test	Significance	Decision
1	The distribution of failure duration is the same across categories of machine type.	Independent-Samples Mann-Whitney U Test	0.506	Retain the null hypothesis.
2	the distribution of hazard level is the same across categories of machine type.	Independent-Samples Mann-Whitney U Test	0.836	Retain the null hypothesis.

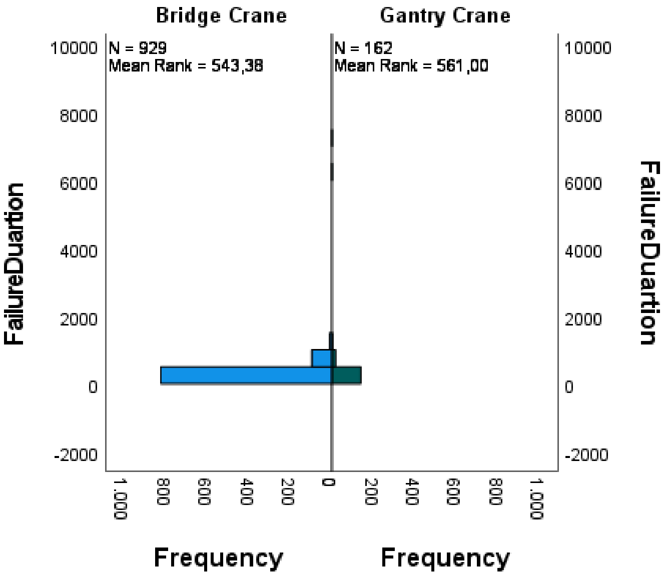

Figure 4. Mann-Whitney U test on Failure Duratio

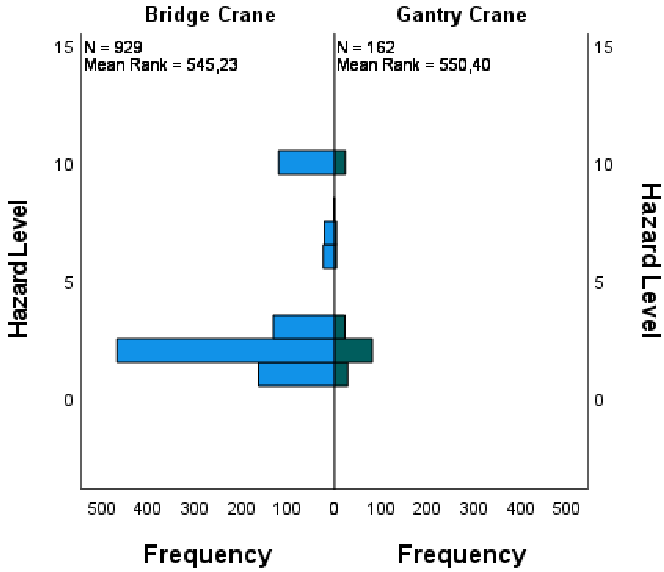

Figure 5. Mann-Whitney U test on Hazard Level

After comparing data regarding two different types of cranes, the second part of testing was performed to determine if there was a difference between bridge and gantry cranes with different capacities and spans. Nine following groups are tested: Double girder bridge crane with capacity of 10 tons and span of 29 meters, Double girder bridge crane with capacity of 16 tons and span of 27 meters, Double girder bridge crane with capacity of 20 tons and span of 16.7 meters, Double girder bridge crane with capacity of 20 tons and span of 22.5 meters, Double girder bridge crane with capacity of 32 tons and span of 24 meters, Single girder bridge crane with capacity of 10 tons and span of 22.5 meters, Single girder bridge crane with capacity of 5 tons and span of 29 meters, Gantry crane with capacity of 63 tons and span of 18 meters, River gantry crane 160/50t. The results are given in Tables 7 and 8, and the summary view is given in Table 9.

Table 7. Kruskal-Wallis test on Failure Duration

Total N	1091
Test Statistics	2.192[a,b]
Degree of Freedom	8
Asymptotic Significance (2-sided test)	0.975

Table 8. Kruskal-Wallis test on Hazard Level

Total N	1091
Test Statistics	0.239[a,b]
Degree of Freedom	8
Asymptotic Significance (2-sided test)	1.000

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Table 9 shows that the null hypothesis cannot be rejected because the level of significance (p) is greater than 0.05, which means that there is no statistical difference between the samples across the 8 different machine models. The results are graphically represented on Figures 6 and 7.

Table 9. Kruskal-Wallis tests summary

	Null Hypothesis	Test	Significance	Decision
1	The distribution of FailureDuration is the same across categories of Machine	Independent-Samples Kruskal-Wallis Test	0.975	Retain the null hypothesis
2	The distribution of Hazard Level is the same across categories of Machine	Independent-Samples Kruskal-Wallis Test	1.000	Retain the null hypothesis

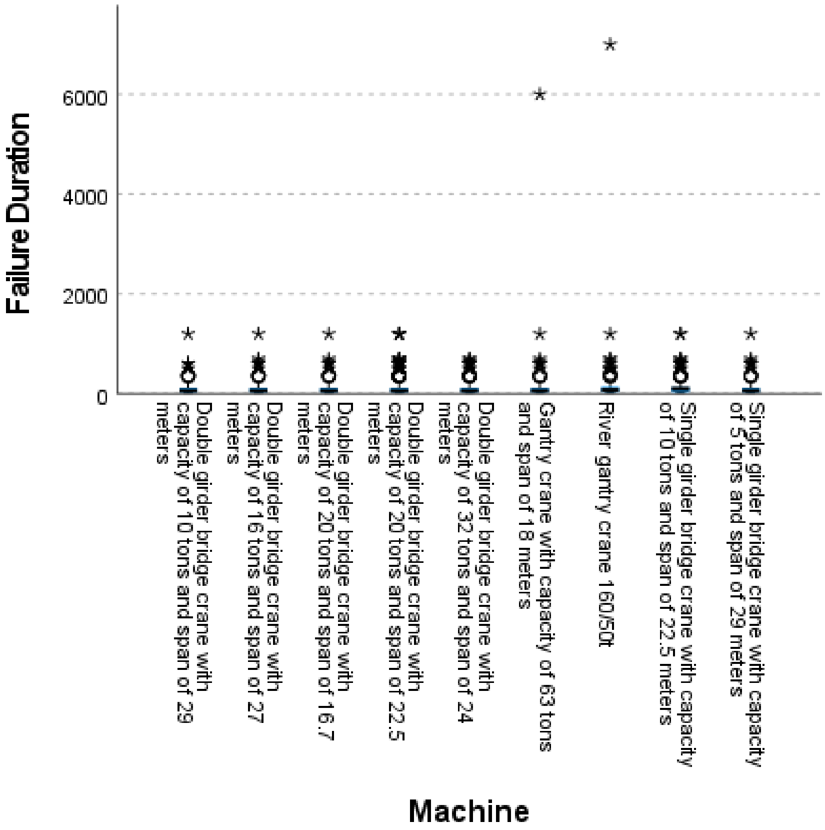

Figure 6. Independent-Samples Kruskal-Wallis test

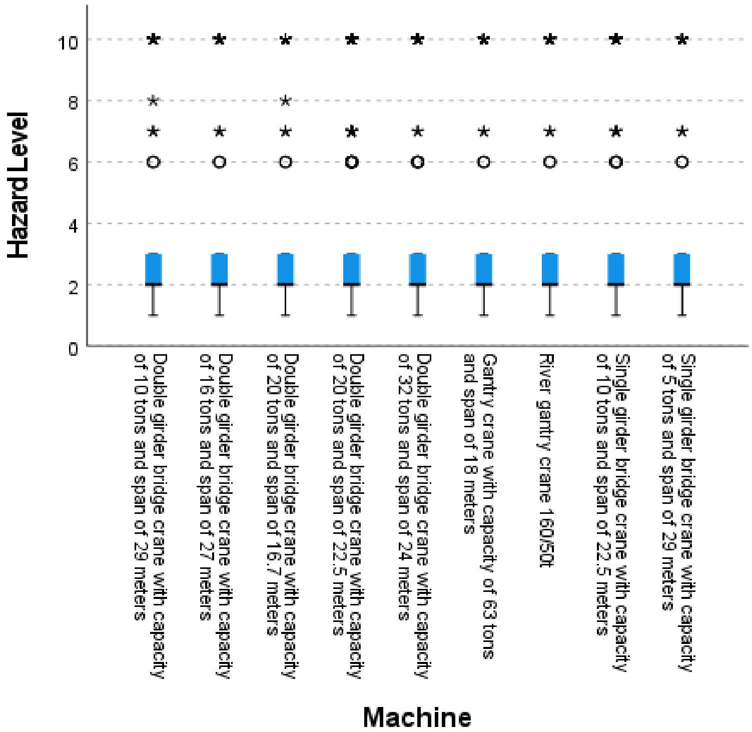

Figure 7. Independent-Samples Kruskal-Wallis test

5 CONCLUSION

The aim of this work is to compare the failure characteristics of different types and models of cranes, i.e. to compare the duration of downtime caused by failure and the levels of hazard that a specific failure can cause betwwen examined machines, in order to consider the possibilities of applying the same maintenance strategies and thereby act preventively to reduce risk from fatal injuries or significant failures of work equipment.

Both normality tests, done on sample size on bridge cranes which contained 931 records regarding seven different cranes and on sample of gantry cranes which contained 160 records regarding two different cranes, showed that the sample does not behave according to a normal distribution, which necessitated the use of non-parametric tests in the hypothesis testing part. Both Mann-Whitney U and Kruskal-Wallis tests are chosen as non-parametric, with fulfiled assumptions that dependent variable should be measured at the ordinal or continuous level, that samples are independant and with independence of observations.

The Mann-Whitney U test showed that it cannot be reliably asserted that there are significant differences between the cranes grouped by type of construction (Bridge and Gantry) both in the duration of failure and in the level of hazard caused by a particular failure. The significance level obtained by this test is p=0.506 for the downtime duration and 0.836 for the hazard level.

When the difference between downtimes between individual groups of cranes depending on their load capacity and span was tested, the Kruskal-Wallis test was used, which showed with significance levels of 0.975 and 1.00 that no significant difference could be concluded between the data.

As the amount of data related to this topic is still small, covering only one year of cranes' work, the proposal for further research would be to increase the number of crane models as well as the amount of data in the sample in sense of time period covered, so that the preventive maintenance method would be optimal.

6 ACKNOWLEDGMENT

This research was funded by Ministry of Science, Technological Development and Innovation of the Republic of Serbia under Contract 451-03-47/2023-01/ 200105 dated February 3, 2023 and RESMOD Saf€ra project.

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Paper submitted: 11.04.2023.

Paper accepted: 11.10.2023.