The Operational Reliability Analysis of Machinery: A Case Study of Forest Forwarders and Their Technological Equipment

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Abstract: Analysis and risk assessment are procedures which help to improve knowledge and are very important in practice. Risk assessment is possible to conduct only on the basis of exact accurate and tested information about the given system, which truly defines the given system within the spatial–temporal context. High standards of maintenance and treatment are closely linked with the requirements for quality and reliability forestry machinery and technological equipment. These standards are closely related to the maintenance of the equipment. This manuscript is focused on the reliability of standard forest machines used in the Slovak forestry. They are relatively modern and useful in the process of transporting and handling trees. This research showed the possibility of decreasing the production costs related to the maintenance of the devices and how to increase the final profit. The results of the research showed that the analysis of reliability is significant regarding to the quality of performed maintenance and the costs paid for it.

Keywords: risk assessment; reliability management; forest machines; maintenance

1. Introduction

Recently, forestry in Slovakia has benefited from a very fast tendency towards developing research at all levels. Increasing demands in terms of the quality of crop treatment in forestry increase the need for highly efficient and reliable forest equipment and technological devices to fulfill the requirement. Nowadays, the forestry industry relies on the wide use of forest machines and devices [1,2].

The advance of international markets, higher customer expectations and the consequent increase in global competition have led manufacturers to create more and more customizable products. Nowadays, manufacturers need to produce high-quality products in less time. In this competitive environment, manufacturers aim to produce high-quality products in the minimum amount of time, which leads to the manufacturers’ greater than ever interest in the machines’ reliability [3,4]. Maintenance is an essential part of manufacturing systems to ensure that operating equipment remains in healthy condition, reduce failures, and guarantee the high quality of products [5]. Moreover, there are additional factors that motivated this growing interest in reliability, which include the increased sophistication and complexity of systems [6], and insistence on product quality, warranty programs, safety laws, and supply chain sustainability [7]. Some of the latter factors are also influenced by the high cost of failures, their repairs or replacement [8].

Problems with ensuring the operational reliability of forest stands are complicated by some specific factors, e.g., assortment machines, number of users, differences in the complexity of the construction of different machines, seasonality in the use of forestry machines, high demands on the qualification of operators, dispersion of equipment over a large area, lack of storage space, as well as operating and weather conditions [9].
The selection and reliability of construction components have a significant impact on the reliability of the final product. Reliability is a very complicated category, and it is not easy to define only on the basis of the theoretical analysis of the project. There are often necessary formal tests where the expected operational conditions are simulated, which evaluate the object from operational time and failure occurrence points of view. In real time operation, there are various factors that lead to the failure of repairable systems. These failures can be categorized into different types for failure pattern analysis and multiple failure modes. Moreover, failures belonging to one mode lead to the occurrence of other modes of failure [10].

Testing is important for many reasons. The results of tests are often necessary for taking decisions (quality point of view), by providing a means of reliability evaluation (e.g., maintenance) as well as a planning and choice making process. Adequate testing leads to high-reliability results and very good quality [11,12].

Reliability engineering focused on the maintenance and lifetime of machines as an engineering discipline consists of the systematic application of the values throughout a device’s lifecycle so that reliability can be checked from the beginning (i.e., concept plan) to the end (i.e., wearing out of the device). Reliability technicians can define reliability requests, estimations, testing, assessments and optimize the system performance due to reliability possibilities used under the real operational conditions. These modifications facilitate infrastructures for business development, but also create new and unknown failures, unknown financial, technological and functional relations among systems within a machine or a device.

Reliability forecast means the assessment of a construction prior to the current design of the structure. Although equipment reliability is not only increased by evaluation techniques, the outcome of the reliability forecast offers an early indication as to whether a design is likely to meet reliability goals. This points to potential reliability issues in a new construction or design modifications, and designates which parts need further testing. It is a method to assess the reliability of a device or determine whether it needs further modifications in early stages, to work efficiently for the corporation [13,14].

We encounter terminology like quality and reliability in everyday life. Producers emphasize them in advertisements in which they highlight the quality of their products, however, the new owner seldom thinks about a product’s limited reliability and only thinks about it when a product breaks down [13,15]. Breakdowns can arise from human failure—by accident or deliberately. The goal of this manuscript was to evaluate the operational reliability of forest forwarders used in Slovak forestry. These machines are employed for processing wood in real conditions. It is necessary to say that under Slovak conditions, this type of study is quite unique because these are not so common due to the purchase price of such types of machines. This is also the case abroad.

2. Materials and Methods

Firstly, it is necessary to state and justify what the data are, what they are typical of, as well as how and to what extent they were collected. The data were collected according to certain construction groups of the machines. The data were collected in MS Excel to facilitate treatment for further analysis. The forwarders were no more than 3 years old at the time of study and the machines were in the period of normal use.

According to the data from the first information obtained from the observed group of machines, it was possible to define a theoretical indicator of reliability for the whole group of machines. Every distribution has its own area for usage, its own parameters, formulas for calculations and tables. Normal distribution and Weibull distribution are the most commonly used methods in the process of assessing the operational reliability of forest machines [1,2]. The advantage of the Weibull distribution is its right side asymmetry of probability density. Due to this asymmetry, the statistical values of reliability indicators are not equal in comparison with normal distribution. Quite often, Weibull distribution is used to determine the theoretical distribution of probability during the solving of a question.
in the field of machine objects’ reliability. This distribution is applied to data modeling regardless of whether the failure intensity is rising, falling or constant. Weibull distribution is flexible and adaptable for data from a wide range [16–18]. One of the advantages of using Weibull distribution is that the failure rate can have a rising, falling or constant trend [19].

Firstly, it is necessary to sort the individual values in ascending order \( i = 1, 2, 3, \ldots, n \). For the estimation of the distribution, function \( F(t) \) is used as the order statistic with the median order. Usually, Bernard’s approximation is used to calculate the median order [1,19]:

\[
F_i(t) = \frac{i - 0.3}{n + 0.4} \tag{1}
\]

where:

- \( F_i(t) \) — estimate of median value (-);
- \( i \) — rank of serial numbers of time to failure \( t \);
- \( n \) — total number of failures.

Then, linear regression is used to obtain the results of the Weibull distribution. This represents the approximation of values by the least-square fit of a straight line. The following relations represent the derivation of calculations of the shape parameter \( \alpha \) and the scale parameter \( \beta \) of the Weibull distribution from the distribution function \( F(t) \):

\[
F(t) = 1 - \exp\left[-(t/\beta)^\alpha\right] \tag{2}
\]

\[
1 - F(t) = \exp\left[-(t/\beta)^\alpha\right] \tag{3}
\]

\[
\ln[1 - F(t)] = -(t/\beta)^\alpha \tag{4}
\]

\[
\ln\left[1/(1 - F(t))\right] = (t/\beta)^\alpha \tag{5}
\]

\[
\ln\left\{\ln\left[1/(1 - F(t))\right]\right\} = \alpha \cdot \ln(t) - \alpha \cdot \ln(\beta) \tag{6}
\]

After simple mathematical modifications and two logarithms, the distribution function \( F(t) \) can be transformed into a line equation:

\[
y = k \cdot x + q \tag{7}
\]

where:

- \( y \) — dependent variable;
- \( x \) — independent variable;
- \( k \) — slope of a line;
- \( q \) — point of intersection of the line with the x axis and y axis, in absolute terms.

The \( x \) axis and \( y \) axis are represented by

\[
x = \ln(t) \tag{8}
\]

\[
y = \ln\left\{\ln\left[1/(1 - F_i(t))\right]\right\} \tag{9}
\]

The least-square fit of a straight line is used to find the line equation, where it is necessary to solve a set of equations in normal form:

\[
q \cdot \sum_{i=1}^{n} x_i + k \cdot \sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} x_i y_i \tag{10}
\]

\[
n \cdot q + k \cdot \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i \tag{11}
\]

Then, the coefficient \( k \) and \( q \) can be counted by

\[
k = \frac{n \cdot \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} y_i}{n \cdot \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \tag{12}
\]
It is also important to verify the statistical significance of the calculated regression equation. For this purpose, the coefficient of determination $r^2$ was used, which can be interpreted as the ratio of the sum of squares of the aligned (predicted) values and the sum of the squares of the observed values. The coefficient of determination $r^2$ is defined by

$$r^2 = \frac{(n \cdot \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} y_i)^2}{n \cdot \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \cdot \frac{n \cdot \sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2}{n \cdot \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}$$

(14)

The coefficient of determination takes values between 0 and 1. If the coefficient of determination approaches 1, it is a strong dependence. Otherwise, if the coefficient of determination approaches 0, it is a weak dependence.

The authors used Visual Basic to calculate the parameters of the Weibull distribution. Programmed algorithms were used to easily calculate the results when changing the input data, which helps to refine reliability characteristics.

The values of the Weibull distribution parameters (Figure 1) for the time to failure $t$ can be counted by

$$\alpha = k$$  

(15)

$$q = -\alpha \cdot \ln(\beta)$$  

(16)

$$\ln(\beta) = -\left(\frac{q}{\alpha}\right)$$  

(17)

$$\beta = \exp\left[-\left(\frac{q}{\alpha}\right)\right]$$  

(18)

where:

$\alpha$—shape parameter of the Weibull distribution;

$\beta$—scale parameter of the Weibull distribution.

The observation was held under real working conditions with a company running a wood processing business following all service requirements. The study in question was conducted in the state where the company managing the largest areas in the Slovak Republic operates, which is also the owner of the biggest number of these technologies in the country. The company has its own maintenance workshops with qualified staff for routine and non-route maintenance.

The results were obtained with the help of observed objects, software and statistical methods. These are going to solve the problem of maintenance costs and provide more effective operational conditions.

The objective of this research was to improve the operational reliability of forest forwarders by John Deere under the real working conditions of the company Forests of the Slovak Republic (state-owned company). A list of the equipment with their working hours is shown in Table 1.

| Forwarder by JOHN DEERE | Production No. of the Machine | Time of Running during Observation Period (Mth) |
|-------------------------|-------------------------------|-----------------------------------------------|
| WJ810D001829 *          |                               | 6821                                          |
| WJ810D001136             |                               | 4700                                          |
| WJ810D001001             |                               | 2629                                          |
| WJ810D001002             |                               | 2811                                          |
| WJ810D001110             |                               | 9680                                          |
The main ways of reliability testing are defined by four elementary steps, namely those from 2 to 5:

- All machines (forwarders) owned by the company were taken for analysis. The purchase price of the machines was too high to neglect their maintenance. This is the reason why the company needed the best possible solution for the configuration of the maintenance system. The human factor impact was not an object of the study because during the time of observation, the root cause of the components’ damage was the only mechanical issue not caused by human factor;
- The analysis was based on working relations where data about the technology were recorded (features of the technology, working relations, etc.);
- The aim of performing tests focused on quality was to define as many failures as possible, with the purpose of elucidating their origins and what each failure might mean in terms of their technological definitions;
- Quantitative results defined possibilities for forecasting a digital value for reliability factors;
- The complexity of the data and the summaries from the quality and quantitative analysis present the failures and interactions among them that are most relevant to reliability.

The reliability evaluation and testing used conditions that are also shown in European standards. The exact method for the research into forwarders according to the mentioned procedure of reliability analysis is as follows in steps 1–5:

1. Machine data sheet design for each machine separately: this obtained technical information about the machine, collected working tasks and drawings;
2. The design of component groups in every machine: this enables recording the outputs from the maintenance records. The machines were divided into the following component groups: bogie (including bodywork, springs, dampers, chassis, wheels, tires, wheel bearings, brakes, steering, etc.) gears and gearing mechanisms (clutches, gearboxes, shafts, joints, differentials, gears with angular belts, chain gears, etc.), engine (fuel system, engine block and other engine parts, cylinders, head of cylinders, piston and their parts, etc.), lubrication and cooling systems, electrical controlled parts of the machine (including sensors), hydraulic system of the machine, hydraulic crane, cabin and controlling elements;
3. Collected data in the statistical program for every single device; this enabled to define the failures and determine how to evaluate the measurement;
4. Definition of the uniform data sheet for every single device: i.e., every data sheet had the same structure that provided universality and possibility to repeat the measurements and record them;
5. Obtained data were evaluated via statistical software.

3. Results

Equations (19)–(24), needed for calculations related to the operational reliability of the observed machines, were used to obtain the results. The results were presented in the following Figures 1–6 and Tables 2 and 3. Statistical software and modern processes were involved in obtaining the operational reliability results.

| Table 2. Details of one factorial analysis of variance for all forwarders focused on mean operating time to failure (MOTTF). |
|---------------------------------|----------------|----------------|----------------|
| Sum of Squares | Degrees of Freedom | Variance | Fisher F Test | p Level of Significance |
|----------------|----------------|-----------|----------------|------------------------|
| Total Diameter | 5,102,590 | 1 | 5,102,590 | 109.5 | 0.000 |
| No. of the Machine | 1,001,150 | 4 | 250,287 | 5.4 | 0.001 |
| Random Factors | 5,217,923 | 112 | 46,589 |             |                      |
Table 3. Basic details of the statistical characteristics for all forwarders.

| No. of the Machine | No. of Measurements (Failures) | MOTTF (Mth) | Coefficient of Variation $\sigma^2$ | Standard Deviation $\sigma$ | 95% Interval of Reliability |
|--------------------|-------------------------------|-------------|------------------------------------|----------------------------|-----------------------------|
|                    |                               |             |                                    |                            | Lower Limit | Upper Limit |
| 810-829            | 38                            | 172.30      | 15,959.09                          | 126.33                     | 130.78       | 213.83      |
| 810-136            | 15                            | 359.14      | 225243.63                          | 474.60                     | 96.32        | 621.97      |
| 810-002            | 20                            | 131.95      | 24021.09                           | 154.99                     | 59.42        | 204.49      |
| 810-001            | 15                            | 148.59      | 33328.55                           | 182.56                     | 47.49        | 249.69      |
| 810-110            | 25                            | 538.00      | 311281.42                          | 557.93                     | 307.70       | 768.30      |

One factorial table of variance for the individual forwarders (f810D-829, f810D-136, f810D-001, f810D-002, f810D-1110) was created in the statistical software STATISTICA 7 to focus on the mean operating time to failure (MOTTF) in operational engine hours (Mth), as shown in Table 2.

Engine hours (Mth) is a quantity measured for machines and engines without which the amount of work performed or power input could not be measured. It is typical for, e.g., tractors as well as forest and construction machines.

Line 1 in Table 2 defines the probability if the total average values of MOTTF are equal to zero. The total average value of MOTTF for individual forwarders (f810D-829, f810D-136, f810D-001, f810D-002, f810D-1110) is not equal to zero $H_1: \mu \neq 0$ which means that $p = 0.000$. From Figure 1 and Table 2, we see that the time to failure for individual forwarders varies statistically significantly. This means that not all forwarders showed the same failure.

![Figure 1](image-url) Graph for 95% confidence intervals of reliability for mean operating time to failure for individual forwarders.

Standard deviation $\sigma$:

$$\sigma = \beta \cdot \sqrt{\Gamma \left( \frac{2}{\alpha} + 1 \right) - \Gamma \left( \frac{1}{\alpha} + 1 \right)^2}$$  (19)
Coefficient of variation $\sigma^2$:

$$\sigma^2 = \beta^2 \cdot \left[ \Gamma\left(\frac{2}{\alpha} + 1\right) - \left(\Gamma\left(\frac{1}{\alpha} + 1\right)\right)^2 \right] \quad (20)$$

Calculation of 95% confidence intervals of reliability for MOTTF to individual forwarders are as follows:

$$\left\{ \left( \text{MOTTF} - t_{\alpha/2,n-1} \cdot \frac{\sigma}{\sqrt{n}} \right); \left( \text{MOTTF} + t_{\alpha/2,n-1} \cdot \frac{\sigma}{\sqrt{n}} \right) \right\} \quad (21)$$

where:
- $t_{\alpha/2,n-1}$—value of t-distribution for half of the confidence interval of reliability and certain degrees of freedom:
- $n$—number of measurements;
- $\sigma$—standard deviation.

Then, there was a calculated failure rate $\lambda(t)$ obtained from the Weibull distribution for forwarders F810D-829 (Figure 2), F810D-136 (Figure 3), F810D-001 (Figure 4), F810D-002 (Figure 5) and F810D-1110 (Figure 6).

The following calculation was derived from the formula for the calculation of the failure rate $\lambda(t)$ of the Weibull two parametric distribution (only for the parameter of size $\alpha$ and the parameter of shape $\beta$, because the parameter of the position was $\gamma = 0$), where:

$$\lambda(t) = \frac{\beta}{\alpha} \left( \frac{t}{\alpha} \right)^{\beta-1} \quad (22)$$

$$\lambda(t) = \frac{\alpha}{\beta} \left( \frac{t}{\beta} \right)^{\alpha-1} = \frac{f(t)}{R(t)} \quad (23)$$

Probability of failure $F(t)$:

$$F(t) = 1 - \exp\left[ -\left( \frac{t}{\beta} \right)^{\alpha} \right] \quad (24)$$

Figure 2. Cont.
Figure 2. Failure rate $\lambda(t)$ for the forwarder f810D-829.

Figure 3. Failure rate $\lambda(t)$ for the forwarder f810D-136.
Figure 3. Failure rate $\lambda(t)$ for the forwarder f810D-136.

Figure 4. Failure rate $\lambda(t)$ for the forwarder f810D-002.

Figure 5. Cont.
Figure 5. Failure rate $\lambda(t)$ for the forwarder f810D-001.

Figure 6. Failure rate $\lambda(t)$ for the forwarder f810D-1110.
As the last indicator of reliability, there was a defined MOTTF. For all the observed machines, Weibull distribution and prediction were used, obtaining:

\[ \text{MOTTF} = \alpha \cdot \Gamma \left( 1 + \frac{1}{\beta} \right) \]

(25)

\[ \text{MOTTF} = \beta \cdot \Gamma \left( 1 + \frac{1}{\alpha} \right) \]

(26)

where:

- \(\alpha, \beta\)—are the parameters of Weibull distribution;
- \(\Gamma\)—gamma function (table value).

Mean operating times to failure (MOTTFs) for the types of machines and individual forwarders are shown in Table 4.

**Table 4.** Mean operating times to failure (MOTTFs).

| Type/No. of the Machine | Mean Operating Time to Failure MOTTF (Mth) |
|-------------------------|------------------------------------------|
| f810D-829               | 172.3                                    |
| f810D-136               | 359.1                                    |
| f810D-001               | 148.6                                    |
| f810D-002               | 132.0                                    |
| f810D-1110              | 538.0                                    |
| f                         | 270                                      |

The evaluation of the results of the operational deployment of individual machines is important for the further evaluation of operational reliability. An interesting comparison is the plot of the total operational deployment (Mth), the total maintenance and repair costs for individual machines (EUR) and the number of replaced spare parts for the observed period in pieces (Figure 7). From this graphical representation, it is clear that the monitored machines form a very diverse set of data. To clarify, it is good to mention other operational data for monitored forwarders (Table 5).

**Table 5.** Operational data monitored by forwarders.

| Machine Type | Year | Number of Failures | Repair and Maintenance Costs (EUR) | Number of Parts Replaced | Number of Hours Worked Per Year (Mth) | Machine Performance in m³ |
|--------------|------|--------------------|-------------------------------------|--------------------------|--------------------------------------|--------------------------|
| 810-829      | 2014 | 7                  | 3983.32                             | 36                       | 1390                                 | 9120.76                  |
|              | 2015 | 8                  | 11,226.84                           | 54                       | 1510                                 | 9897.35                  |
|              | 2016 | 10                 | 7795.13                             | 59                       | 1425                                 | 9345.58                  |
|              | 2017 | 4                  | 2079.42                             | 22                       | 1605                                 | 10,413.75                |
|              | 2018 | 10                 | 8523.65                             | 45                       | 891                                  | 5871.09                  |
|              | Total| 39                 | 33,604.36                           | 216                      | 6821                                 | 44,648.53                |
| 810-136      | 2014 | 0                  | 0.00                                | 0                        | 324                                  | 2304.06                  |
|              | 2015 | 0                  | 0                                   | 0                        | 476                                  | 3564.56                  |
|              | 2016 | 5                  | 10,111.34                           | 30                       | 821                                  | 576.3                    |
|              | 2017 | 5                  | 50,274.59                           | 28                       | 2168                                 | 14,868,64                |
|              | 2018 | 6                  | 8068.39                             | 41                       | 911                                  | 6747.86                  |
|              | Total| 99                 | 14,454.32                           | 4700                     | 33,245.42                            | 33,245.42                |
| 810-001      | 2014 | 0                  | 0.00                                | 0                        | 430                                  | 3000.77                  |
|              | 2015 | 0                  | 0                                   | 0                        | 520                                  | 3690.77                  |
|              | 2016 | 3                  | 2877.36                             | 18                       | 301                                  | 2150.44                  |
|              | 2017 | 6                  | 3073.5                              | 35                       | 659                                  | 4690.22                  |
|              | 2018 | 6                  | 4076.54                             | 39                       | 719                                  | 5010.88                  |
|              | Total| 92                 | 10,027.40                           | 2629                     | 18,543.08                            | 18,543.08                |
Table 5. Cont.

| Machine Type | Year | Number of Failures | Repair and Maintenance Costs (EUR) | Number of Parts Replaced | Number of Hours Worked Per Year (Mth) | Machine Performance in m³ |
|--------------|------|--------------------|-------------------------------------|--------------------------|--------------------------------------|--------------------------|
| 810-002      | 2014 | 0                  | 0.00                                | 0                        | 325                                  | 3700.09                  |
|              | 2015 | 0                  | 0                                   | 0                        | 425                                  | 4560.26                  |
|              | 2016 | 4                  | 2662.67                             | 27                       | 140                                  | 1600                     |
|              | 2017 | 8                  | 6102.22                             | 45                       | 814                                  | 9235.89                  |
|              | 2018 | 9                  | 7413.14                             | 43                       | 1107                                 | 12654.2                  |
|              | Total| 21                 | 15580.03                            | 115                      | 2811                                 | 31750.44                 |
| 810-1110     | 2014 | 2                  | 716.17                              | 8                        | 1250                                 | 16980.13                 |
|              | 2015 | 5                  | 4598.17                             | 28                       | 2640                                 | 36500.87                 |
|              | 2016 | 6                  | 6182.08                             | 41                       | 2430                                 | 34380.45                 |
|              | 2017 | 6                  | 2599.69                             | 29                       | 2204                                 | 30283.19                 |
|              | 2018 | 7                  | 4449.79                             | 22                       | 1156                                 | 15880.56                 |
|              | Total| 26                 | 18545.9                             | 128                      | 9680                                 | 134025.2                 |
| 2014         | 9    | 4699.49             | 44                                  | 3719                     | 35105.81                             |
| 2015         | 13   | 15825.01            | 82                                  | 5571                     | 58213.81                             |
| 2016         | 28   | 20028.58            | 175                                 | 5117                     | 53236.77                             |
| 2017         | 29   | 19125.42            | 159                                 | 7450                     | 69491.69                             |
| 2018         | 38   | 32533.51            | 190                                 | 4784                     | 46164.59                             |
| 2014–2018    | Total| 117                | 92212.01                            | 650                      | 26641                                | 262212.67                |

Figure 7. Basic operating data of the observed machines (forwarders) for the monitored period.
The necessity of reliability is a very significant feature of every product. The outputs of this research can be summarized in many areas.

Another and no less important characteristic of reliability is the failure rate, which represents the probability that a mechanical object that has not broken down before operational time “t” will break down immediately after operational time t 15. This leads to increased operating costs, as does a too short maintenance period. A too long maintenance period means increased costs due to the inappropriate technical state of the device.

4. Conclusions

For these forwarders, the machine number f810D-1110 had the highest time to failure, but not the largest number of failures. This means that this machine was loaded in operation very often and that the number of operational engine hours was very high, but the number of failures was not the largest in comparison with other observed machines. The closest to the machine was the forwarder number f810D-136 which concerns the failure rate as well as the mean time to failure. On the other hand, the forwarder number f810D-002 had the lowest failure rate. The time differences between failures were statistically significant between machines.

On the basis of the collected and analyzed data, there were modified stocks of spare parts in the observed company. The fast-movable spare parts were added to the stock for fast change and maintenance. The company offered further data for future cooperation in the area of forest machines to improve the stocks of spare parts also for other types of machines, which highlights the effectiveness of the maintenance and increases the business possibilities for the company in the market. The stock was modified for fast movable spare parts and the maintenance staff were well prepared for maintenance of the machines they need for everyday business.

The purposeful processing of documented maintenance information can offer a wide range of data, not only about the background of the machine, but also about the whole service system. The main objective of this analysis was to frequently improve the maintenance strategy, which is closely related to the modifications in terms of dependability and the overall productivity of the machine. Further examples of the evaluation of maintenance management data can be found, and the best maintenance policy related to unit costs for this example is a predictive maintenance [20,21]. The advantages of statistical models are not only their ability to calculate the optimal interval of predetermined maintenance and optimal diagnostic records for predictive maintenance. These also offer an actual indication that predetermined preventive maintenance pushes up the working reliability of system. The decision lies with the maintenance specialists, whether or not they apply the designs and methods for improving the maintenance efficiency of industrial production equipment [16,22].

The results present positive solutions for the working utilization of forwarders in companies applying these machines under real working conditions. This evaluation presents how one may mitigate costs for maintenance services, the time for their execution, and define the stock of service pieces and finally increase profit. The analysis showed that the research into reliability was very useful with regard to maintenance and costs.

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