# Research on reliability of forest harvester operation used in the company Lesy Slovenskej Republiky

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**ABSTRACT**: The paper deals with reliability of forest harvesters. They are quite modern and helpful in the process of tree felling. The quality of felling is important for the further quality of wood used in wood processing industry. The quality of machines is connected with time for which a machine is able to operate without any breaks caused by repairs and failures. Maintenance is the way how to realize and extend the time for reliability of machines used in felling. This research has shown how to decrease the costs of maintenance, time for its execution, manage the store of spare parts and finally increase profits of felling companies. The research has confirmed that the observation of reliability is very useful regarding the quality of maintenance and its costs. The importance of harvesters in the forest economy increases because it brings profit.

**Keywords**: reliability; forest machines; maintenance; harvester

Integrated technologies on the basis of multi-operational machines represent progressive systems of wood harvesting and processing in the operational area: shrubby – manipulation place (Dvořák et al. 2011).

In every firm a number of production equipment items can be found for which a standard maintenance system based on the operating time of machines is applied. However, the used maintenance intervals (periods) are often determined just based on a qualified estimate of the manufacturer or maintenance manager. This leads to an increase of machinery operating costs – a too short maintenance period results in an increase of maintenance costs, too long maintenance intervals lead to an increase of costs due to the poor technical condition of production equipment (Drożyner, Mikołajczak 2007).

Diagnostics and maintenance have to provide all activities in the operation process, to eliminate losses, accidents and to produce high quality products (Kučera, Marko 2008). They require a good philosophy and co-operation between other managers. Using methods for risk analysis helps to discover weak points and to reduce losses (Moubray 1997). In practice, operational reliability is determined by the number of failures per unit time during the time under consideration (called the failure rate) (Drożyner, Mikolajczak 2007) depending on probability, time, performance and operating conditions.

Considering the failure rate of a product, let us suppose that a large group of items is tested or used until all fail, and that the time of failure is recorded for each item. Plotting the cumulative percent of failures is time dependent (Mooren 1991). Reliability $R(t)$ decreases with time; an item that has just been tested and shown to meet specification has a reliability of 1 when first placed into service. Unreliability $F(t)$ increases with time. Since the product has either survived or failed at any time $t$, the sum of reliability and unreliability must be 1, i.e.:

$$F(t) = 1 - R(t) \quad (1)$$

where:
$R(t)$ – reliability,
$F(t)$ – unreliability.

One of the other ways of determining an optimal standard maintenance period is the application of renewal (replacement) theory in the field of maintenance using maintenance data recorded in a maintenance information system. The practical output of such application for a maintenance manager is the possibility of justified correction of preventive maintenance periods, based on the results of algorithmic testing of data recorded in the maintenance information system (Müller 2007).

The machine operator greatly affects the output of the harvester. In recent work studies of single grip harvesters the difference between work outputs of experienced harvester operators has been as much as 40% or more (Väätäinen et al. 2004).

The importance of product reliability is a very significant aspect of each device. The outputs of this research can be resumed from many points of view.

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The purposeful processing of long-term documented maintenance data can provide a plenty of information not only about a machine's history, but also about its maintenance system. The main objective of data analysis is to continually improve the maintenance efficiency, which is closely related to improvements in dependability and overall productivity of the production equipment. Further examples of evaluation of maintenance management data can be found in Legát (1999).

The aim of the paper is a model evaluation of operational reliability of harvesters used in forest economy of the Slovak Republic. These machines are analysed for processing wood in the real conditions.

## MATERIAL AND METHODS

Reliability prediction deals with evaluation of a design prior to the actual construction of the system. Although the product reliability is not increased by the prediction process, the result of reliability prediction provides an early indication as to whether a design is likely to meet reliability goals, points to potential reliability problem areas in a new design or design modifications, and identifies components needing further testing. It is a tool to determine as early as possible whether the equipment will be reliable enough or whether it needs further improvement to function successfully for the company (Bowles 1992; Dupow, Blount 1997; Ormon et al. 2002).

Different parameters that impact ergonomics and work conditions were measured directly at workplaces in the actual working conditions (primarily no. of failures, no. of changed components, operational time, machine performance) (Gerasimov, Sokolov 2009). The research was realized in the company Lesy Slovenskej republiky, s.r.o. This is a very important fact because the company follows all service requirements. Requested results were obtained with the help of observed objects, software and statistical methods. They will solve the problem of maintenance costs and create more effective operational conditions.

The methodology is based on the observation and analysis of operational parameters recorded in real conditions. The material of the research can be divided into categories of observed objects (three John Deere harvesters) and statistical methods evaluated by STATISTICA 7 statistical software.

The main methods of reliability analysis consist of four basic stages (Kováčová 2010):

- *functional and technical analysis* where the first data on a system are collected (characteristics of a system, functional and technical characteristics),
- *quality analysis* goal is to find out all failures, reasons for their origin and description of a system that can cause a particular failure,
- *quantitative analysis* provides the estimation of numerical values for reliability indicators,
- *synthesis* of data and conclusions from quality and quantitative analyses directly show failures and their combinations which the system reliability is the most dependent on.

The reliability analysis used conditions defined in Slovak technical standards based on European standards. The exact procedure for the research of harvesters according to the above-mentioned methods of reliability analysis is as follows (Kováčová 2010):

- creation of a machine card for each device individually. Machine card obtained technical data of a device, resume of working and a drawing of it,
- definition of constructional groups for each machine. This helped to record outputs from service notes,
- creation of folders in MS Excel for each device. It helped to classify failures and perform the analysis of a device,
- creation of a universal table for each device, i.e. each device had the same structure, which guaranteed the uniformity and repeatability of records and the whole research,
- collected data were analysed using mathematical statistics. The results are presented in graphical and tabular forms.

#### Time between failures

The model of the time between failures of one-factor ANOVA for observed objects is described by the mathematical formula of Eq. (2) as follows:

$$t_{ij} = \bar{t} + a_i + e_{ij} \quad (2)$$

where:

$t_{ij}$ – time between failures at level $i$ of a factor and number $j$ of repeatability (h),

$\bar{t}$ – total average time between failures (h),

$a_i$ – impact of level $i$ of a factor,

$e_{ij}$ – random deviation from the average value at level $i$ of a factor and number $j$ of repeatability,

$i$ – machine type or machine number,

$j$ – number of a failure in particular machine types or numbers of machines.

One-factor ANOVA was used to analyse the significance of differences among particular machines. The hypothesis $H_0$ versus the hypothesis $H_1$ was tested:

$$H_0 : \bar{t} = 0 \text{ versus } H_1 : \bar{t} \neq 0$$

$$H_0 : a_i = 0 \text{ versus } H_1 : a_i \neq 0$$

#### Weibull distribution and failure intensity

The failure intensity λ($t$) was calculated from the Weibull distribution of John Deere harvesters. The parameters of the Weibull distribution are shown in Table 4. The calculation was done using Eq. (3):

$$\lambda(t) = \frac{b}{a} \times \left(\frac{t}{c}\right)^{b-1} \quad (3)$$

where:

$a$ – scale parameter,

$b$ – shape parameter,

$c$ – location parameter and equals zero.

Table 1. Operational parameters of observed harvesters manufactured by John Deere

| Machine type | Year | No. of failures | No. of changed components | Operational time (h·yr$^{-1}$) | Machine performance (m$^3$·yr$^{-1}$) |
|---|---|---|---|---|---|
| John Deere 1270 | 2005 | 9 | 38 | 360 | 6,462 |
| | 2006 | 42 | 229 | 1,905 | 32,453 |
| | 2007 | 52 | 252 | 2,710 | 50,679 |
| | 2008 | 14 | 58 | 675 | 12,560 |
| | 2009 | 36 | 163 | 1,710 | 31,823 |
| | 2010 | 50 | 222 | 2,423 | 44,846 |
| | total | 203 | 962 | 9,783 | 178,823 |
| John Deere 1070D | 2005 | 10 | 50 | 535 | 5,614 |
| | 2006 | 10 | 47 | 476 | 4,915 |
| | 2007 | 6 | 29 | 299 | 3,000 |
| | 2008 | 14 | 59 | 675 | 6,057 |
| | 2009 | 41 | 183 | 1,965 | 20,253 |
| | 2010 | 33 | 127 | 2,068 | 24,315 |
| | total | 114 | 495 | 6,018 | 64,154 |
| John Deere 770 | 2005 | 7 | 37 | 395 | 2,052 |
| | 2006 | 3 | 13 | 160 | 870 |
| | 2007 | 5 | 21 | 245 | 1,597 |
| | 2008 | 10 | 55 | 489 | 3,187 |
| | 2009 | 36 | 183 | 1,862 | 10,614 |
| | 2010 | 26 | 137 | 1,359 | 8,747 |
| | total | 87 | 446 | 4,510 | 27,066 |
| Total | | 404 | 1,903 | 20,311 | 270,042 |

### Mean time between failures $T_S$

The mean time between failures $T_S$ was calculated according to Eq. (4):

$$T_S = \bar{t} = a \times \varsigma\left(1 + \frac{1}{b}\right) \cong a \qquad (4)$$

where:

$a$, $b$ – Weibull parameters,

$\varsigma$ – gamma function (tabular value).

## RESULTS AND DISCUSSION

During the research the following reliability characteristics were analysed: time between failures, failure intensity and mean time to failure.

The first data on the observed machines were collected according to the test plan (*n, R, t*), where *n* means the number of observed machines, *R* means the number of failed objects during the time of observation (*t*). In research a two-point model of data collection was used, i.e. an object was either in operation or not. Operational data are shown in Table 1. Harvesters were produced in 2005 and they were bought by the company Lesy SR in the same year.

Using the STATISTICA 7 mathematical statistical software we obtained statistical data on parameters of operational reliability of all John Deere forest harvesters.

Using the STATISTICA 7 statistical software the basic table of one-factor ANOVA was calculated for particular forest harvesters (John Deere 1070D vs. John Deere 1270, John Deere 1270 vs. John Deere 770,

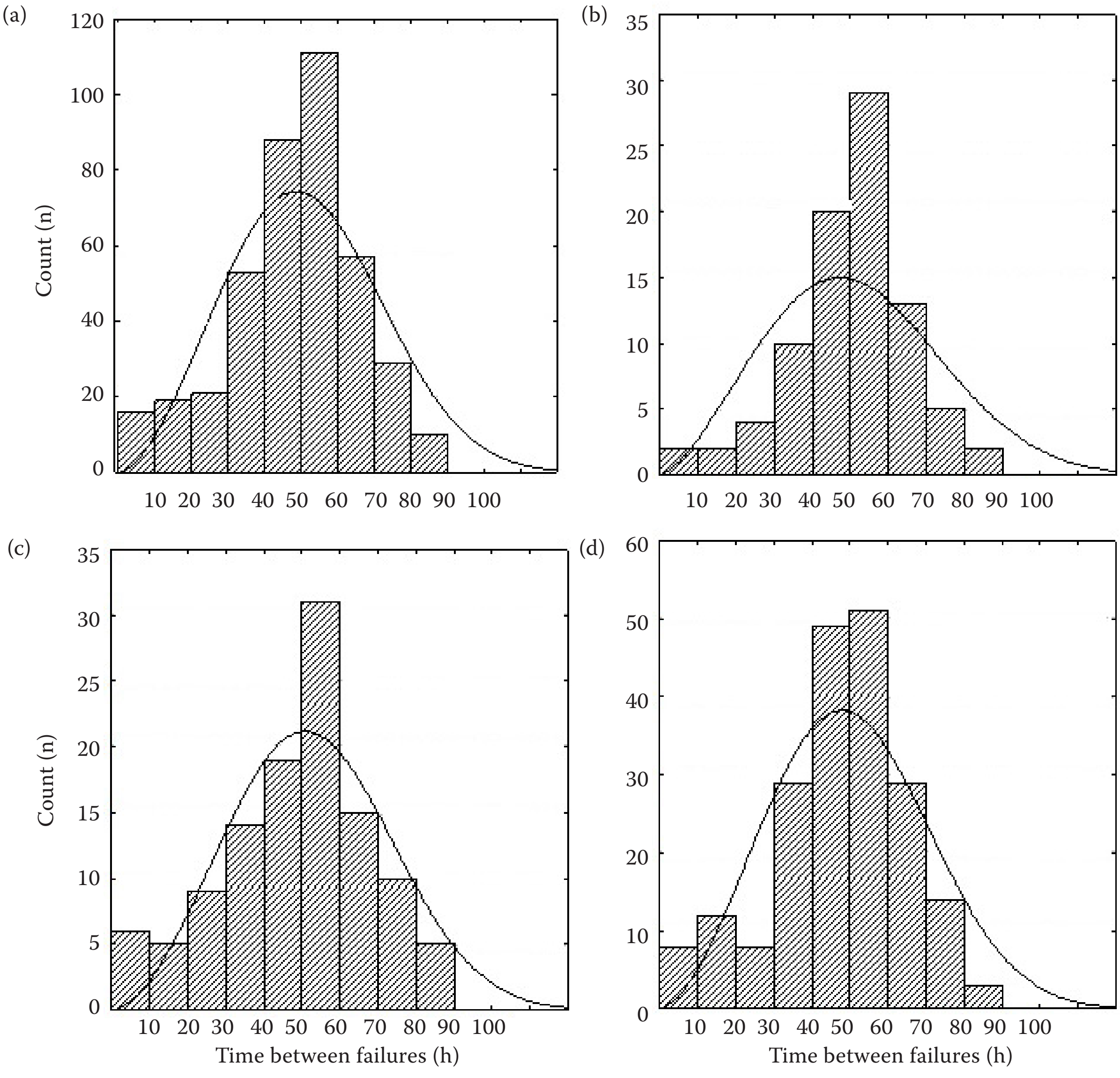


Fig. 1. Probability density of the time between failures in harvesters – (a) all harvesters, (b) John Deere 770, (c) John Deere 1070D, (d) John Deere 1270

Table 2. Basic table of one-factor ANOVA for forest harvesters regarding the time between failures in operational hours

| | Sum of squares | df | $s^2$ | $F$-test | $P$ |
|---|---|---|---|---|---|
| Model of failures | 866,226.5 | 1 | 866.226.5 | 2,737.3 | **0.000** |
| Machine No. | 698.1 | 2 | 349.1 | 1.1 | 0.333 |
| Random factors | 126,897.3 | 401 | 316.5 | | |

df – degrees of freedom, $s^2$ – variance, in bold – statistically significant

John Deere 1070D vs. John Deere 770) regarding the time between failures in operational hours (Table 2).

The first line in Table 2 shows a probability whether the total average value of times between failures equals zero. The total average value of times between failures for particular forest harvesters (John Deere 1070D vs. John Deere 1270, John Deere 1270 vs. John Deere 770, John Deere 1070D vs. John Deere 770) does not equal zero, i.e. $H_1$: $\bar{t} \neq 0$ is true ($P$ = 0.000).

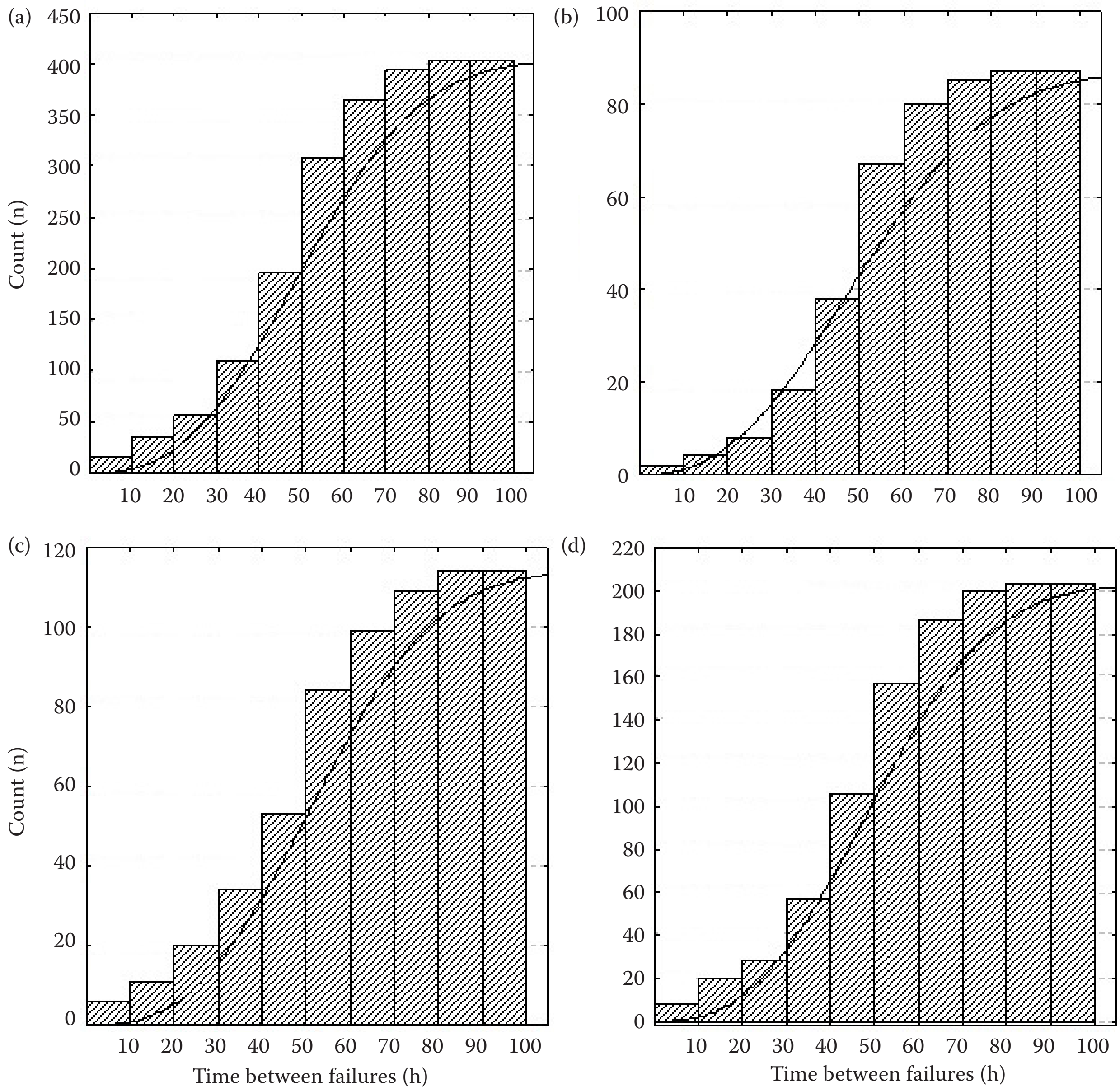


Fig. 2. Distribution function of the time between failures in harvesters – (a) all harvesters, (b) John Deere 770, (c) John Deere 1070D, (d) John Deere 1270

Table 3. Basic statistical characteristics of particular forest harvesters

| Machine type | Mean time between failures | SE | SD | CV | 95% Confidence interval | | Count |
|---|---|---|---|---|---|---|---|
| | | | | | left margin | right margin | |
| John Deer 770 | 51.1 | 1.9 | 17.8 | 34.8 | 47.3 | 54.8 | 87 |
| John Deer 1070D | 48.9 | 1.7 | 17.8 | 36.3 | 45.7 | 52.2 | 114 |
| John Deer 1270 | 47.7 | 1.2 | 17.8 | 37.3 | 45.2 | 50.2 | 203 |

SE – standard error; SD – standard deviation; CV – coefficient of variation

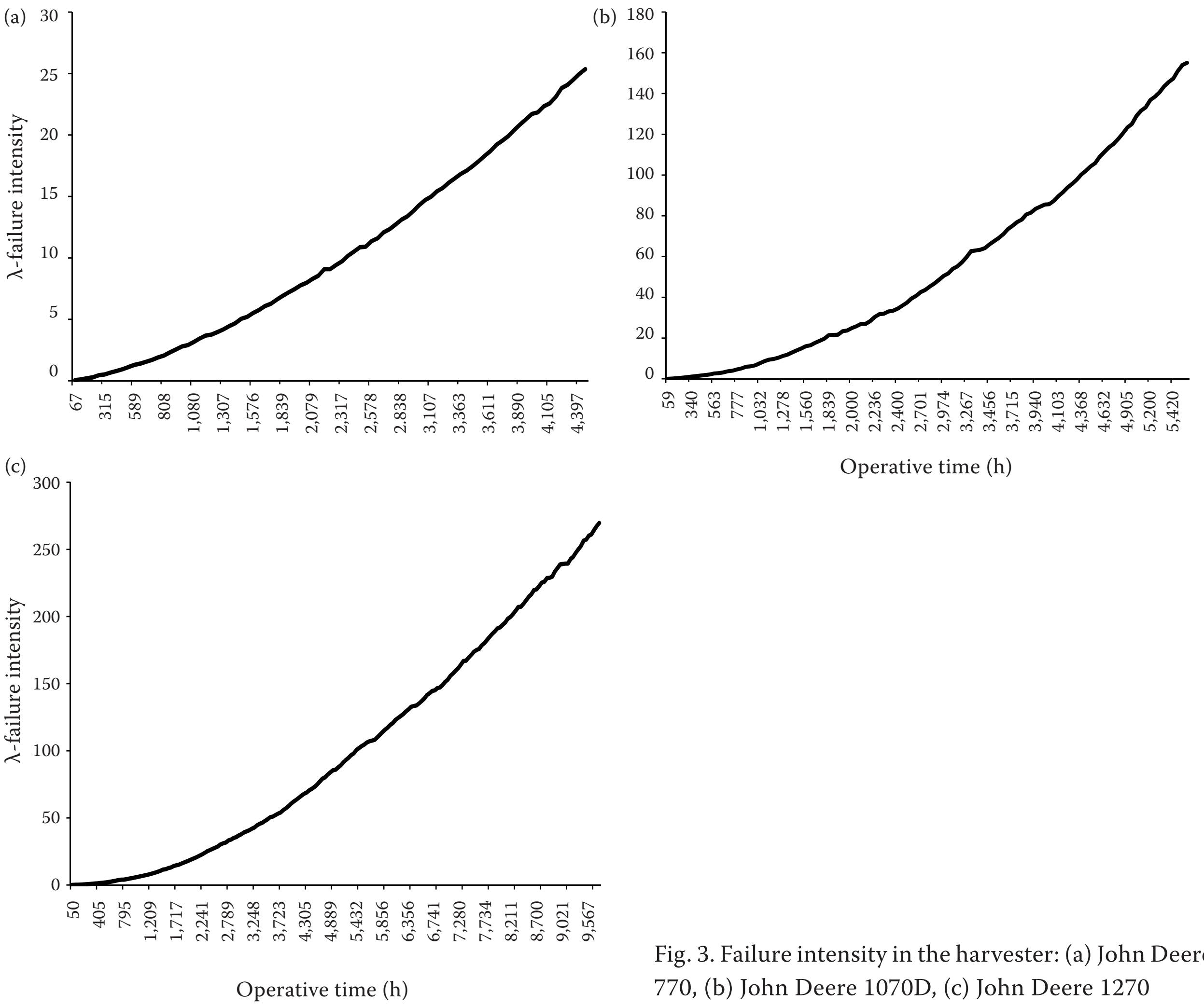


Fig. 3. Failure intensity in the harvester: (a) John Deere 770, (b) John Deere 1070D, (c) John Deere 1270

In the second line of Table 2 it is documented that the time between failures of the forest harvester John Deere 1070D vs. John Deere 770 is not statistically more significant than that of the forest harvester John Deere 1270 vs. John Deere 770 and John Deere 1070D vs. John Deere 1270. It means that the values of time averages between failures are only randomly higher.

A table of the basic statistical characteristics for particular forest harvesters was calculated in the following step (Table 3). The listed values are important for further research activities and analysis.

Using the STATISTICA 7 statistical software curves of density probability for the time between failures (Fig. 1) and curves of a distribution function for the time between failures (Fig. 2) were constructed. The researched values bring a new approach to the system of maintenance in the company. They explain and evaluate maintenance possibilities for the observed harvesters.

The mean times between failures $T_S$ for observed harvesters are shown in Table 4. The failure intensity $\lambda(t)$ of harvesters John Deere is presented in Fig. 3.

Table 4. The parameters of Weibull distribution

| Machine type | Scale parameter $a$* | Shape parameter $b$ | Location parameter $c$ | Count ($n$) |
|---|---|---|---|---|
| John Deer 770 | 58.1178 | 2.4733 | 0 | 87 |
| John Deer 1070D | 59.3918 | 2.7840 | 0 | 114 |
| John Deer 1270 | 56.7171 | 2.6826 | 0 | 203 |
| Average | 57.7619 | 2.6646 | 0 | 404 |

*mean operational time between failures $T_S$ (h)

## CONCLUSION

The results bring positive solutions for the operational use of harvesters in organizations using these technologies in practice. This research has shown how to decrease the costs of maintenance, time for its execution, manage the store of spare parts and finally increase profits of felling companies. The research showed that the observation of reliability is very useful regarding the quality of maintenance and its costs. The importance of harvesters in the forest economy increases because it brings profit.

From the research outputs we can predict a lot of data regarding the intensity of failures after the five-year research period. We can suppose that the frequency of failures is going to increase. It means that the time between failures will be shorter. Research on harvester failures was interesting also from the aspect of costs. Costs necessary for maintenance were also observed. The most expensive spare part of particular harvesters was the maintenance of a hydraulic crane. The highest intensity of failures occurs in the part of the hydraulic system of machines and worn cutting tools of a harvester head.

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