Weibull’s analysis of the dependability of critical components of selected agricultural machinery

David Fabiánek (0000-0002-7946-6772), Václav Legát (0000-0001-7070-1388), Zdeněk Aleš (0000-0002-2517-1215)
Faculty of Engineering, Czech University of Life Sciences Prague, Department for Quality and Dependability of Machines, Kamýcká 129, 165 21 Prague 6 – Suchdol, Czech Republic, E-mail: fabianekd@tf.czu.cz, legat@tf.czu.cz, ales@tf.czu.cz

Article abstract
The aim of this paper is an analysis of the dependability of critical components of the John Deer 7530 tractor. For this analysis data was used from a database which contains maintenance data of 166 tractors during approx 9 years. The first part of this article is devoted to the selection of critical components based on number of failures of individual machine parts for a given period and their sales prices. The next part of article presents data for calculation dependability indicators which contains operating times to failure and operating times without failure. Due to the large size of the data files of the individual components, the data are only given for one machine component. Furthermore, the method of calculation of dependability indicators is described by parametric statistical methods according to ČSN EN 61649:2009 and mean time to operating failure. The results of the analysis are summarized in tables and graphs. The method in this article can be used to optimise the maintenance program.

Keywords
Dependability, Weibull distribution, Agriculture, Tractor

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1 Introduction

At present, manufacturing companies face great pressure from a highly competitive environment and are forced to search new ways to improve production of quality and reduce production costs [1, 2]. In a constant effort to make the production processes more effective, which aims to achieve a higher level of prosperity and competitiveness of the company, the importance of care for tangible assets is growing, especially the importance of reliability of production equipment (further just “PE”). Great emphasis is placed on keeping PE in high readiness, which generates demanding requirements for their maintenance. By a suitable setting of the maintenance policy, it is possible to significantly extend the operation time until failure, maintenance costs and the life cycle of the PE [3–6]. Many maintenance strategies, policies and methods have been developed, which are aimed at making maintenance cheaper and more effective. Such programs have the minimization of costs, downtime and losses due to failure of critical objects of the equipment as their main objective. Cost minimization improves the effectiveness and profitability of the organization [7–12].

Significant help in building optimal maintenance programs is the knowledge of dependability indicators. Dependability indicators are:

- Density function of operating time to failure \( f(t) \).
- Probability of failure \( F(t) \).
- Reliability function \( R(t) \).
- Failure rate \( \lambda(t) \). \([4, 13]\)

Many authors research the possibilities of optimizing maintenance in different industries. For example train transport [14, 21], warranty policy [15], machining tools [16], or energetics [17]. Therefore, this paper focuses on obtaining indicators of dependability of PE. Therefore, this article focuses on obtaining indicators of dependability in the industry where maintenance managers neglect using indicators of dependability. This paper demonstrates on
10 critical components of a John Deere 7530 tractor the dependability quantification results obtained using the parameters of the Weibull distribution function which can be an important element in optimizing the tractor maintenance program.

2 Materials and methods

For calculate indicators of dependability a database from STROM Praha a.s. was used. The company is exclusive distributor of JOHN DEERE technology for CZ and also an authorized service. The time period in which the maintenance data were acquired is from 4.1.2010 to 28.5.2019. The number of records is 3262. Data were recorded for 166 machines. The operating hour [EH] is used as a unit of operating time. The maintenance record with the smallest wear and tear that appears in the database is 0 EH (probably a pre-sale preparation of the machine) and the largest 19006 EH.

Critical components of PE were selected by this procedure:

1. Determining the number of occurrences of failures of individual components in the monitored period.
2. Deletion of irrelevant records (objects changed within preventive maintenance programs, work operations, connection of diagnostic devices, etc.).
3. To ensure the usability of the calculated dependability indicators, objects with the number of occurrences of failures <10 were removed from the database.
4. The calculate of average prices of components in the monitored period.
5. The criticality was quantified using the equation:

\[ K = n_F \cdot C, \]

Where:
\( K \)……criticaly
\( n_F \)…… number of failures in a given time period [1]
\( C \)…… average prices of the components for the period [EUR/ given time]

6. Division of components into three categories according to their criticality using Pareto analysis in the ratio A = 80 %, B = 10 % and C = 10 % of the total cumulative value of the criterion.

7. Selected objects for further research are listed in Tab.1.

**Tab. 1 Selected components for research according to criticality**

| Nomenclature of components | Name of the nomenclature               | Criticality     |
|---------------------------|---------------------------------------|-----------------|
| RE535729                  | Exhaust gas cooler                    | 1813695.83      |
| SE502330                  | Turbocharger                           | 1543399.18      |
| RE537578                  | Torsional vibration damper             | 449349.35       |
| RE43738                   | Tensile force sensor                   | 352457.50       |
| SE501227                  | Water pump                             | 319146.07       |
| AL160250                  | Three-way brake valve                  | 304104.34       |
| AL168483                  | Fuel pump                              | 69313.17        |
| RE543308                  | ERG valve                              | 2510.23         |
| RE523318                  | Turbo actuator                         | 2453.77         |
| RE167207                  | Engine oil pressure sensor             | 416.62          |
It should be added that when selecting objects for further research, emphasis was placed not only on their cost criticality, but also on operational criticality. This means that only such objects were selected which, due to their failure, make it impossible to perform the required production tasks. This fact significantly contributes to the total maintenance costs due to the associated cost items, which in the case of a tractor can be, for example, its towing, repair in difficult conditions (accident site), higher purchase price due to express delivery time, or production losses resulting from non-compliance with agrotechnical deadlines. The input data for the calculation of the dependability indicators of individual objects are in Table Tab. 2. The table contains operating times until the failure of the object and times without failure, so-called incomplete observations (operating time without failure). Only the data for object RE535729 is given in the article as an example due to the large size of the files.

Tab. 2 Input data for calculation of object dependability indicators RE535729 Flue gas return cooler

| Failure number | Operating time to failure [EH] | Operating time without failure [EH] |
|----------------|-------------------------------|-----------------------------------|
| 2              | 1080  1303  1820  1913  2057  2200  2205  2311  2377  2642  2798 |
| 13             | 2906  2912  2965  2997  3053  3271  3296  3470  3532  3602  3671  3727 |
| 25             | 2906  2912  2965  2997  3053  3271  3296  3470  3532  3602  3671  3727 |
| 37             | 3762  3792  3917  3948  4057  4148  4183  4401  4452  4471  4578  4752 |
| 49             | 4904  4982  5001  5117  5150  5194  5417  5523  5770  5790  5814  5852 |
| 60             | 6109  6225  6350  6381  6530  6715  6750  6954  7214  7277  7331  7373 |
| 72             | 7688  7704  8118  8312  8391  8529  8689  8785  8969  8993  9094  9203 |
| 9363           | 9461  9938  9987  10440  11281  11299  12229  12300  12804  13458  |
| 23             | 135  214  324  357  369  533  583  589  656  700  729 |
| 743            | 819  924  928  944  1001  1004  1007  1187  1244  1324  1385 |
| 1405           | 1412  1428  1442  1543  1647  1746  1872  1933  1940  1972  2119 |
| 2251           | 2625  2646  2797  2814  2816  2905  3093  3051  3057  3084  3088 |
| 3142           | 3213  3244  3255  3311  3317  3467  3503  3539  3541  3576  3655 |
| 3719           | 3780  3782  3983  4041  4095  4218  4320  4333  4345  4368 |
| 4425           | 4435  4498  4511  4602  4683  4762  4789  4833  4849  4913  4946 |
| 4980           | 5094  5300  5337  5380  5474  5523  5854  5918  5927  5928  5945 |
| 5962           | 6007  6066  6112  6196  6247  6262  6395  6429  6497  6499  6500 |
| 6600           | 6604  6884  6965  7060  7125  7335  7346  7435  7578  7674  7706 |
| 7836           | 7932  7962  7988  8055  8132  8219  8413  8431  8549  8570  8625 |
| 8721           | 8798  8901  9200  9380  9386  9444  9495  9540  9803  9956  10141 |
| 10848          | 10904 11293 11300 11527 11781 12095 12326 13388 13427 13713 14160 |
| 14212          | 14844 15170 15790 |
4. Linear regression – linear equation

   a) Calculation of parameter $a$ of shape and $\beta$ scale of Weibull distribution [19, 20]

Furthermore, other dependability indicators were calculated.

1. The Weibull distribution probability density function of operating time to failure

$$f(t) = \frac{a_t}{\beta_t^a} \cdot t^{a_t-1} \cdot \exp \left[ - \left( \frac{t}{\beta_t} \right)^{a_t} \right]$$  \hspace{1cm} (2)

Where:
- $a_t$...Shape parameter of Weibull distribution [-],
- $\beta_t$...Scale parameter of Weibull distribution [-],
- $t$...Operating time to failure [E.H].

2. Reliability function $R(t)$

$$R(t) = \exp \left[ - \left( \frac{t}{\beta_t} \right)^{a_t} \right]$$ \hspace{1cm} (3)

3. Probability of failure $F(t)$

$$F(t) = 1 - \exp \left[ - \left( \frac{t}{\beta_t} \right)^{a_t} \right]$$ \hspace{1cm} (4)

4. Failure rate $\lambda(t)$

$$\lambda(t) = \frac{a_t}{\beta_t} \cdot \left( \frac{t}{\beta_t} \right)^{a_t-1} = \frac{f(t)}{R(t)}$$ \hspace{1cm} (5)

5. Mean Operating Time to Failure $E(t) = MOTTF$

$$MOTTF = \beta \cdot \Gamma \left( 1 + \frac{1}{a} \right)$$ \hspace{1cm} (6)

3 Results and discussion

No dependability analysis performed on similar components from same the agriculture machine monitored for so long time as presented in this article was found in the available literature. There is nothing to compare the results with. From the point of view of the conditions in which the production processes of these branches are realized and from the point of view of the composition of PE, a completely new discipline opens up for research activities - operational dependability and optimization of renewal, which must be given due attention and help practice. Dependability indicators of selected components are in tables Tab. 3–12.
**Tab. 3** Weibull distribution parameters, indicators of reliability from RE535729

| Parameter/indicator | α (shape parameter) | β (scale parameter) | MOTTF [EH] |
|---------------------|---------------------|---------------------|------------|
| reliability         | 1.47                | 13600.88            | 12313.36   |

**Tab. 4** Weibull distribution parameters, indicators of reliability from SE502330

| Parameter/indicator | α (shape parameter) | β (scale parameter) | MOTTF [EH] |
|---------------------|---------------------|---------------------|------------|
| reliability         | 1.43                | 35137.03            | 31935.82   |
**Tab. 5** Weibull distribution parameters, indicators of reliability from RE537578

| Parameter/indicator | α shape parameter | β scale parameter | MOTTF [EH] |
|---------------------|------------------|------------------|------------|
| reliability         | 3.28             | 11683.46         | 10476.91   |

**Tab. 6** Weibull distribution parameters, indicators of reliability from RE43738

| Parameter/indicator | α shape parameter | β scale parameter | MOTTF [EH] |
|---------------------|------------------|------------------|------------|
| reliability         | 0.86             | 36663.36         | 39585.43   |
**Tab. 7** Weibull distribution parameters, indicators of reliability from SE501227

| Parameter/indicator | $\alpha$ shape parameter | $\beta$ scale parameter | MOTTF [EH] |
|---------------------|--------------------------|-------------------------|------------|
| reliability         | 2.86                     | 14739.44                | 13136      |

**Tab. 8** Weibull distribution parameters, indicators of reliability from AL160250

| Parameter/indicator | $\alpha$ shape parameter | $\beta$ scale parameter | MOTTF [EH] |
|---------------------|--------------------------|-------------------------|------------|
| reliability         | 0.71                     | 113460.41               | 141272.9235|
Tab. 9 Weibull distribution parameters, indicators of reliability from AL168483

| Parameter/indicator | $\alpha$ shape parameter | $\beta$ scale parameter | MOTTF [EH] |
|---------------------|--------------------------|-------------------------|------------|
| reliability         | 2.58                     | 22918.67                | 20351.28   |

Tab. 10 Weibull distribution parameters, indicators of reliability from RE543308

| Parameter/indicator | $\alpha$ shape parameter | $\beta$ scale parameter | MOTTF [EH] |
|---------------------|--------------------------|-------------------------|------------|
| reliability         | 1.06                     | 57134.78                | 55783.87   |

![Graph](image-url)
**Tab. 11** Weibull distribution parameters, indicators of reliability from RE523318

| Parameter/indicator | $\alpha$ shape parameter | $\beta$ scale parameter | $MOTTF$ [EH] |
|---------------------|---------------------------|-------------------------|--------------|
| reliability         | 2                         | 23412.96                | 20749.07     |

**Tab. 12** Weibull distribution parameters, indicators of reliability from RE167207

| Parameter/indicator | $\alpha$ shape parameter | $\beta$ scale parameter | $MOTTF$ [EH] |
|---------------------|---------------------------|-------------------------|--------------|
| reliability         | 2.03                      | 21373.55                | 18936.59     |
4 Conclusion

The calculated dependability indicators using equations 2–6 applied to the collected operating data of selected tractor components indicate that further research into the application of statistical methods to optimize the maintenance program of self-propelled production equipment makes sense. Among the critical components of the tractor, there are those in which the results of the failure characteristics indicate that the increase in failure intensity is not accidental in nature. However, this hypothesis needs to be confirmed by further research.

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