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Weibull's Analysis of the Dependability of Critical Components of Selected Agricultural Machinery

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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

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 *λ (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:

$$K = n_F \cdot C, \qquad (1)$$

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.

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. 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

The data were processed using the Weibull analysis with the support of an Excel spreadsheet. The analysis procedure was in accordance with the standard ČSN EN 61649:2009 [18]:

1. Ascending order of input data
2. Bernard's approximation
3. Replacement of a modified distribution function *F(t)*
4. Linear regression – linear equation
   a) Calculation of parameter *a* of shape and *β* scale of Weibull distribution [19, 20]

Furthermore, other dependability indicators were calculated.

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

$$f(t) = \frac{\alpha_t}{\beta_t^{\alpha}} \cdot t^{\alpha_t - 1} \cdot exp\left[-\left(\frac{t}{\beta_t}\right)^{\alpha_t}\right] \qquad (2)$$

Where:
a_t…Shape parameter of Weibull distribution [-],
β_t…Scale parameter of Weibull distribution [-],
t…Operating time to failure [EH].

2. Reliability function $R(t)$

$$R(t) = exp\left[\left[-\left(\frac{t}{\beta_t}\right)^{\alpha_t}\right]\right] \qquad (3)$$

3. Probability of failure $F(t)$

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

4. Failure rate $\lambda(t)$

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

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

$$MOTTF = \beta \cdot \Gamma\left(1 + \frac{1}{\alpha}\right) \qquad (6)$$

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

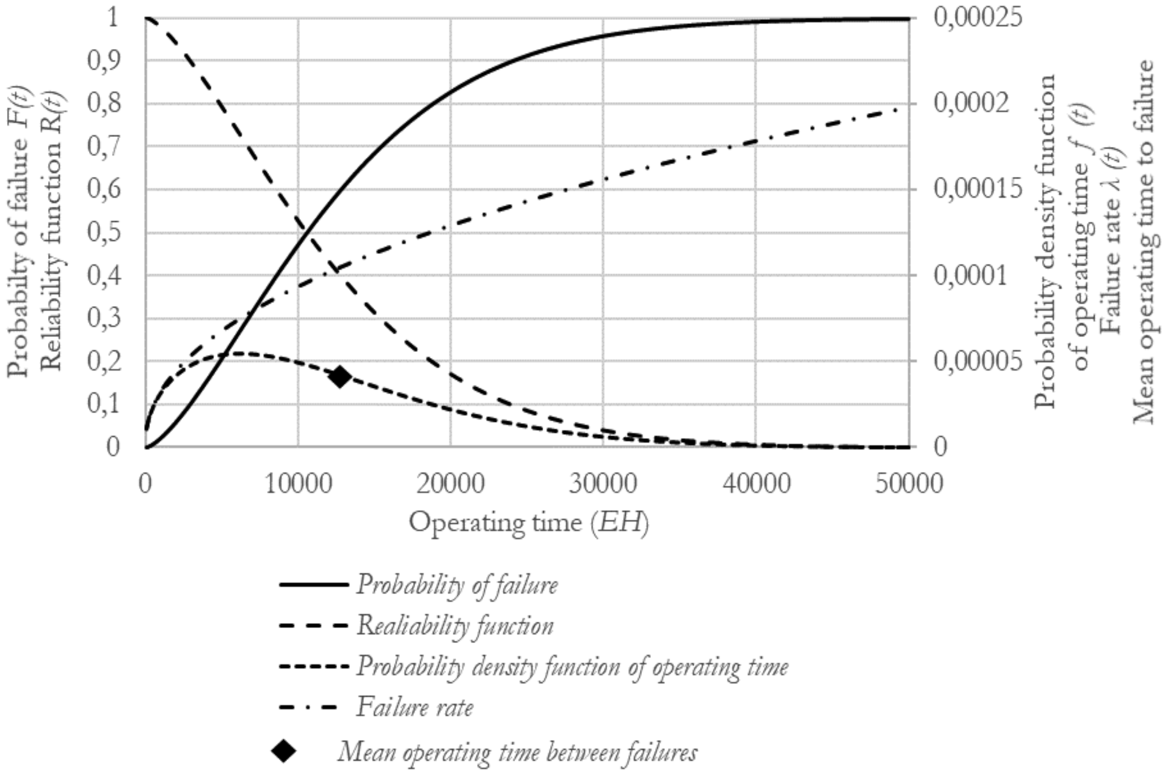
Failure number											
Operating time to failure [EH]											
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2	1080	1303	1820	1913	2057	2200	2205	2311	2377	2642	2798
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2906	2912	2965	2997	3053	3271	3296	3470	3532	3602	3671	3727
25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
3762	3792	3917	3948	4057	4148	4183	4401	4452	4471	4578	4752
37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
4904	4982	5001	5117	5150	5194	5417	5523	5770	5790	5814	5852
49	**50**	**51**	**52**	**53**	**54**	**54**	**55**	**56**	**57**	**58**	**59**
6109	6225	6350	6381	6530	6715	6750	6954	7214	7277	7331	7373
60	**61**	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**	**71**
7688	7704	8118	8312	8391	8529	8689	8785	8969	8993	9094	9203
72	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**	**81**	**82**	
9363	9461	9938	9987	10440	11281	11299	12229	12300	12804	13458	
Operating time without failure [EH]											
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	3033	3051	3057	3084	3088
3142	3213	3244	3255	3311	3317	3467	3503	3539	3541	3576	3655
3719	3757	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								

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.

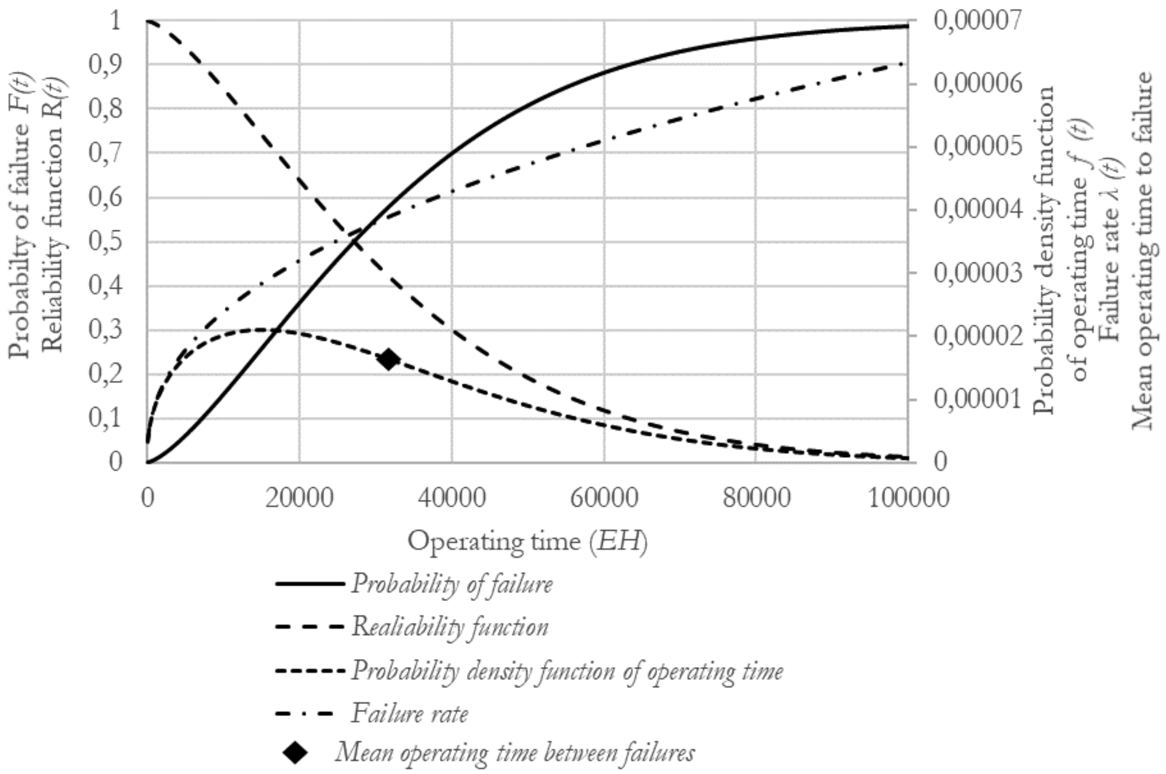
Tab. 3 *Weibull distribution parameters, indicators of reliability from* RE535729

Parameter/indicator	*α* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	1.47	13600.88	12313.36



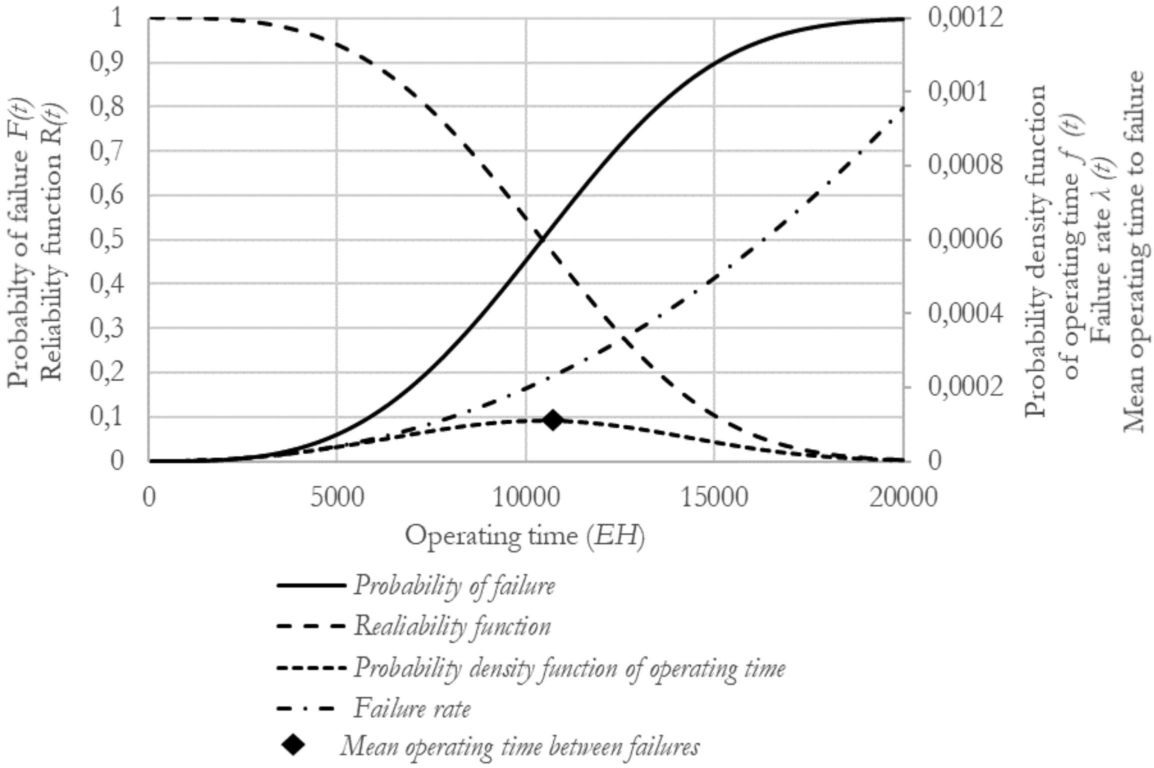
Tab. 4 *Weibull distribution parameters, indicators of reliability from SE502330*

Parameter/indicator	*α* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	1.43	35137.03	31935.82



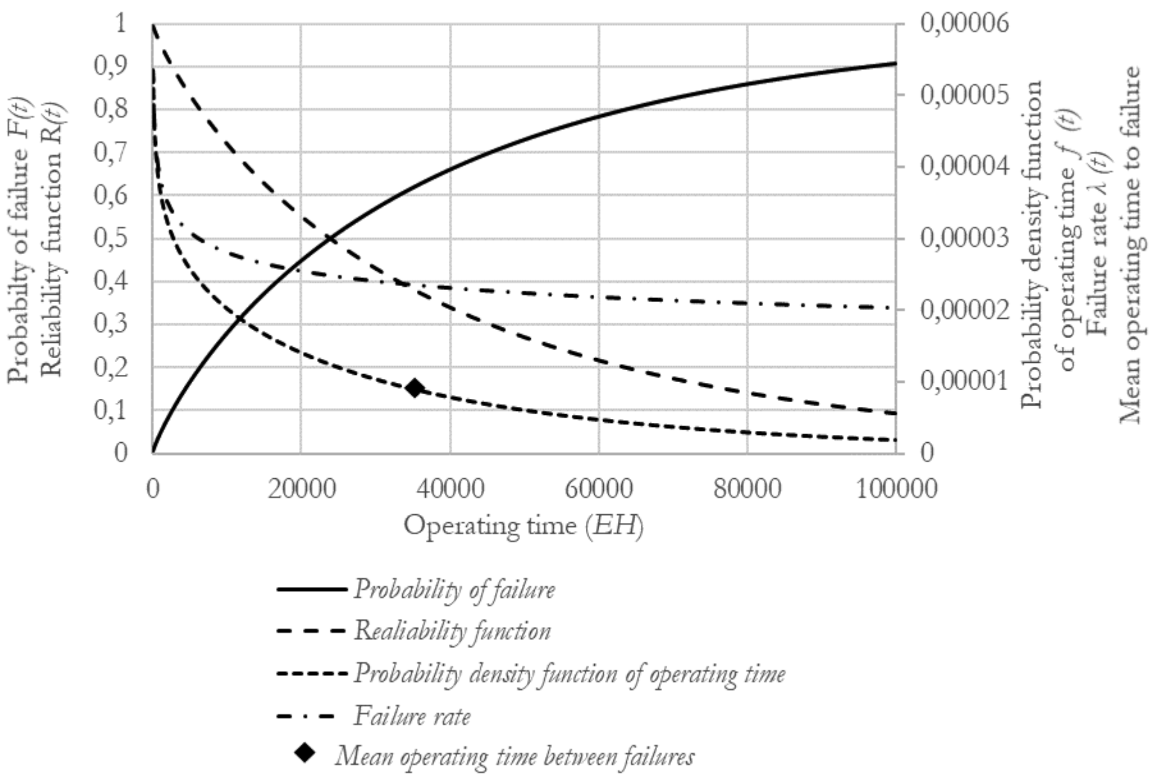
***Tab. 5** Weibull distribution parameters, indicators of reliability from* RE537578

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



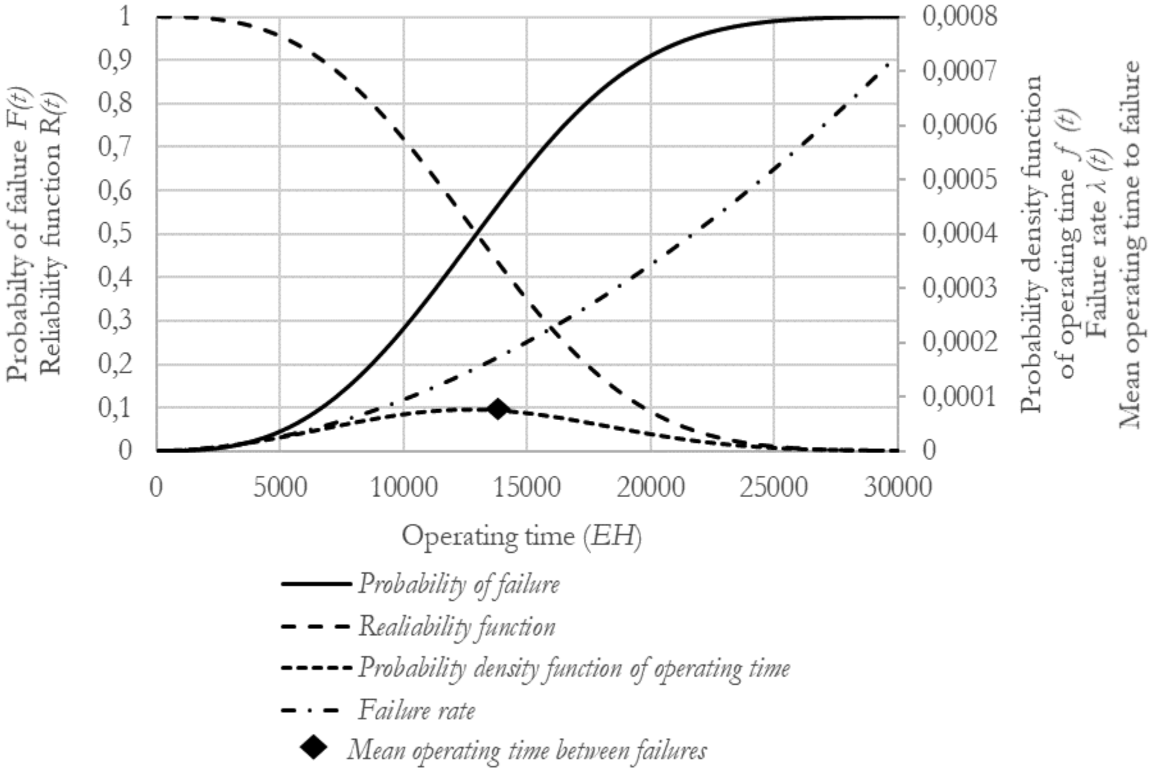
***Tab. 6** Weibull distribution parameters, indicators of reliability from* RE43738

Parameter/indicator	*α* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	0.86	36663.36	39585.43



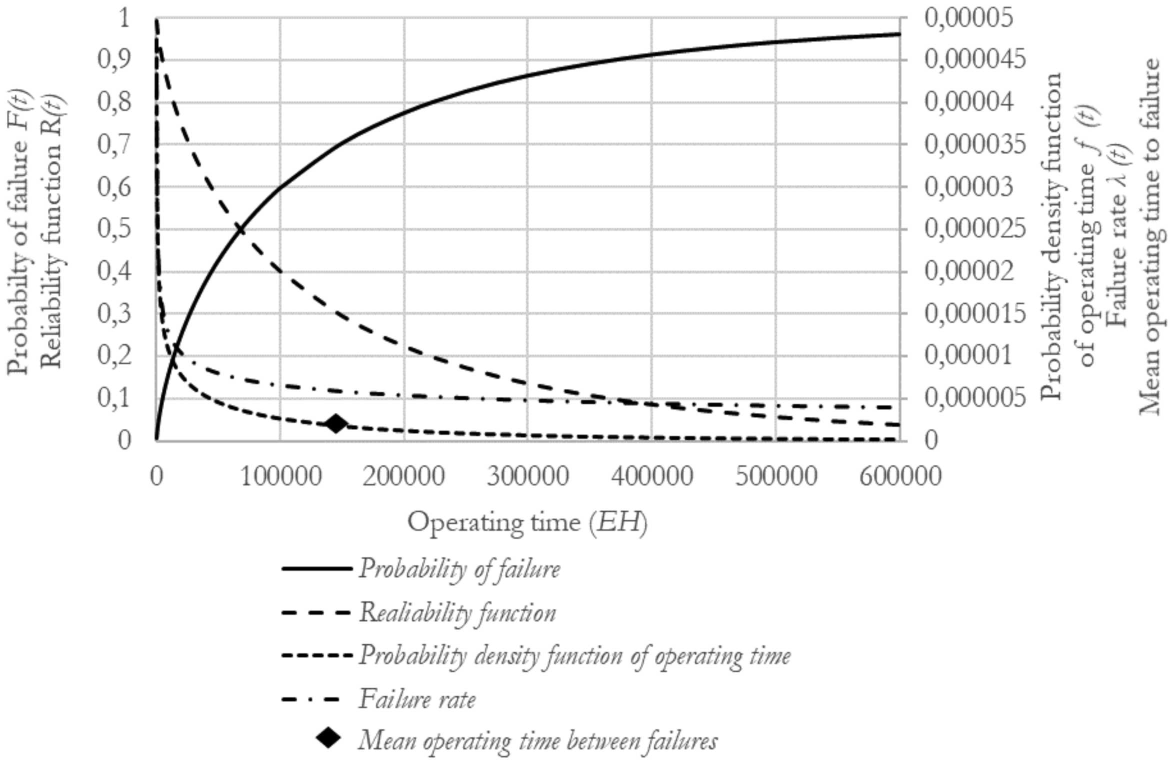
***Tab. 7** Weibull distribution parameters, indicators of reliability from SE501227*

Parameter/indicator	*a* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	2.86	14739.44	13136



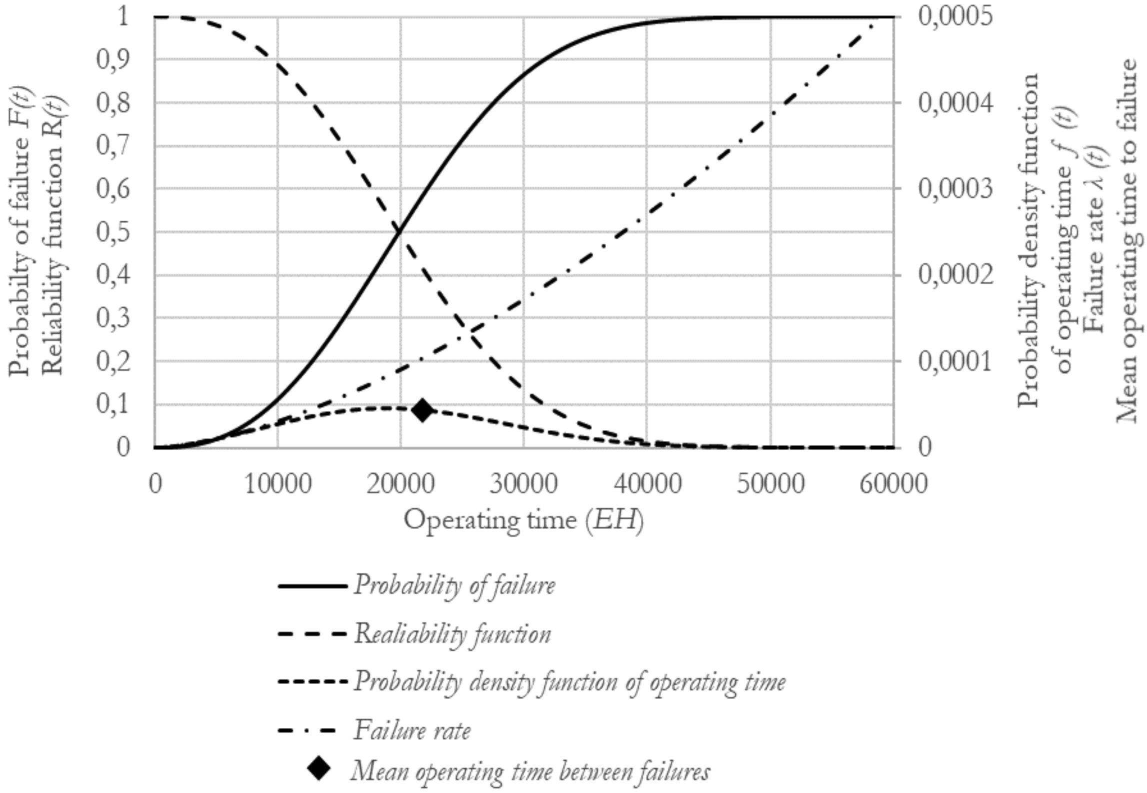
***Tab. 8** Weibull distribution parameters, indicators of reliability from AL160250*

Parameter/indicator	*a* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	0.71	113460.41	141272.9235



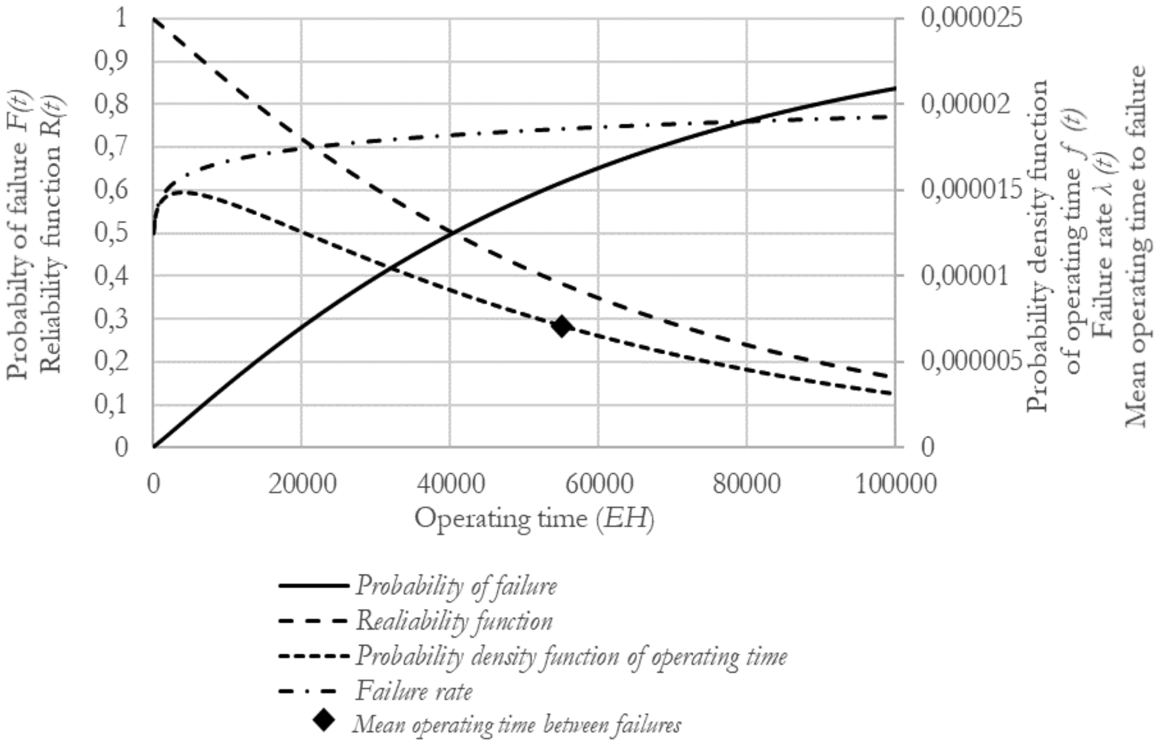
Tab. 9 *Weibull distribution parameters, indicators of reliability from AL168483*

Parameter/indicator	*α* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	2.58	22918.67	20351.28



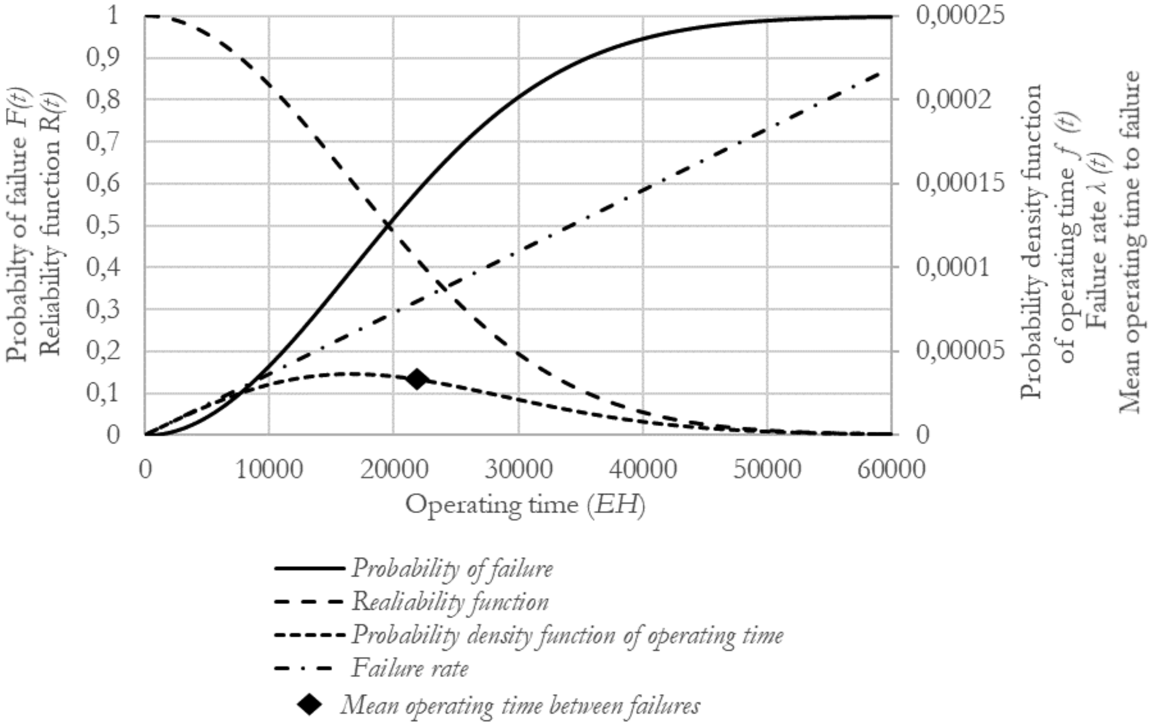
Tab. 10 *Weibull distribution parameters, indicators of reliability from* RE543308

Parameter/indicator	*α* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	1.06	57134.78	55783.87



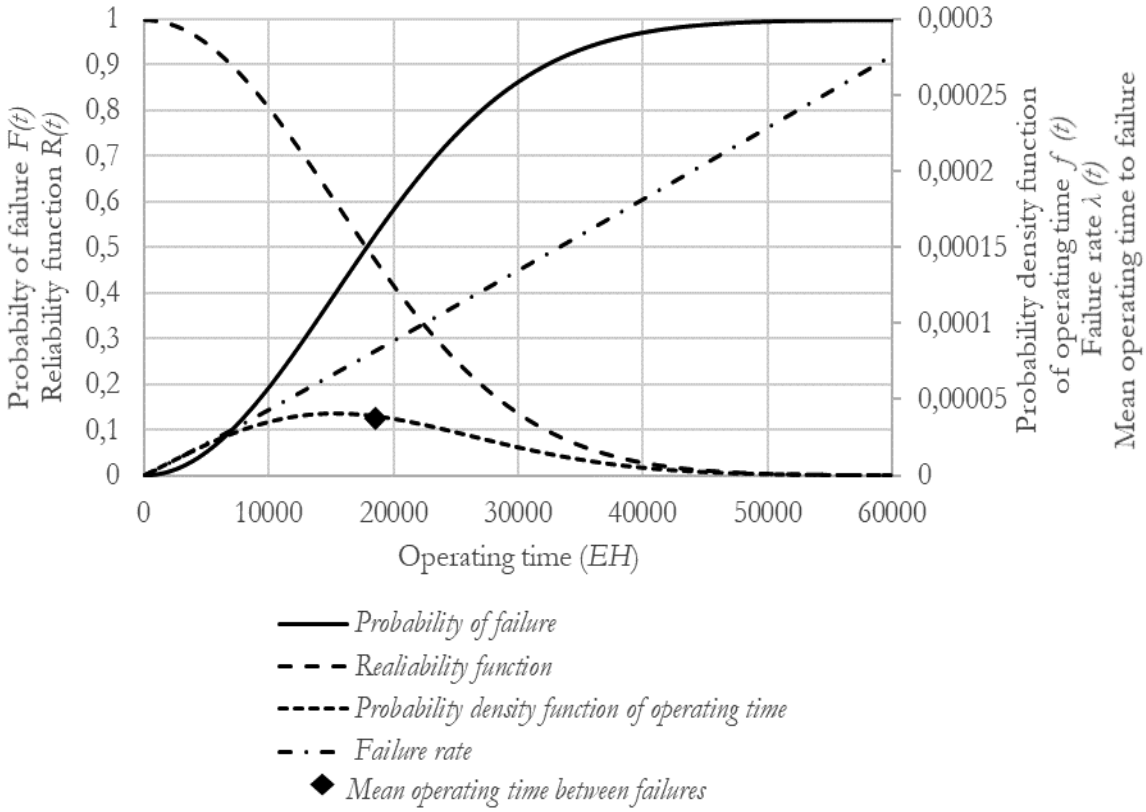
Tab. 11 *Weibull distribution parameters, indicators of reliability from* RE523318

Parameter/indicator	*a* shape parameter	*β* scale parameter	*MOTTF* [EH]
reliability	2	23412.96	20749.07



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

Parameter/indicator	*a* shape parameter	*β* 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 senseAmong 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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