Methodical approach to determine the gamma-percentage resource of aggregates and units of forklift trucks

Ivan Bitunski, Miho Mihov
Agricultural Academy, Sofia

Abstract: *Increasing the efficiency of machine usage for transport services in agricultural holdings can be achieved by creating stocks of aggregates and units in company warehouses based on a predetermined gamma-percentage of available resources.*
This study proposes a methodical approach to determine the 80% of gamma-percentage resource for forklift elements, considering both known and unknown distribution laws for their resources. It includes truncated and repeatedly truncated samples.
The results obtained from this study can be utilized for planning purposes and establishing stock levels to ensure the operational readiness of Bulgarian forklifts.
KEY WORDS: *RESOURCE, GAMMA-RESOURCE, SPARE PARTS, STOCKS, MACHINES, PRODUCTION, WORKING CONDITION, EXTRACT.*

It is well-established that the costs of maintaining a spare parts reserve for machines are significantly lower than the potential losses incurred from their unavailability. Consequently, a significant portion of the inventory is held not out of necessity, but as a precautionary measure. Spare parts warehouses often maintain excess stock due to concerns about shortages.

However, maintaining such reserves involves high costs and ties up working capital. The challenge lies in reducing inventory levels while ensuring high-demand fulfillment.

To address this challenge, it is crucial to know about the resource allocation of machine elements in use. By creating reserves based on a predetermined gamma-percentage resource of core components, efficiency in utilizing machines for transport services in agricultural bases can be improved.

The gamma-percentage resource represents the lower confidence limit of resource dispersion at a one-sided confidence boundary.

$$\beta_0 = \gamma \text{ , where } \gamma = \frac{\gamma\,\%}{100}.$$

When a theoretical distribution law of resource allocation for elements is known, the 80% gamma resource can be calculated using established dependencies,

- normal distribution law.

$$t_\gamma = \bar{t} - U_k(0{,}8).\sigma \quad ,$$

where $\bar{t}$ is the average resource of the element;

$U_k(0{,}8)$ - the quantile of the distribution law;

σ - the assessment of the standard deviation.

- For the Weibull distribution law

$$t_\gamma = U_k(1-0{,}8).a + c,$$

Where “a “ и “c” are parameters of the distribution law;

$U_k(1-0{,}8)$ - the quantile of the distribution law.

Than the 80% gamma-resource of the forklift engine is:

$$t_\gamma = U_k(1-0{,}8).a + c = 0{,}567.23229 + 0 = 13171$$

where a=23229 is parameter of the distribution law;

$U_k(1-0{,}8)$ =0,567 the quantile of the distribution law;

c =0 is parameter of the distribution law.

In this manner, the 80% gamma resource for all primary components of the forklifts is determined when the resource distribution law is known. The obtained results are presented in Table 5.

<u>In cases where the resource distribution law is unknown and a truncated sample is used</u>- if, at the end of the observation period, more than 20% of the objects from the initial sample have exhausted their resource, while the utilization of all remaining objects in working condition surpasses that of the objects reaching the limit state, these steps are followed to determine the 80% gamma resource is performed in two stages:

- The utilization of all tested objects is arranged in ascending order.
- The member of the variation sequence corresponding to the 80% gamma resource is determined using the provided formula.

$$N_{80\%} = \frac{N.80}{100} + 0{,}5 \quad ,$$

where $N_{80\%}$ is the number of the member in the variation sequence whose utilization corresponds to the 80% gamma resource;

N - the number of members in the variation sequence / the number of objects participating in the observation, no.

If a fractional number is obtained, an adjustment is made to the calculated result:

$$T_{80\%} = T_i - \left(T_i - T_{i+1}\right)\left(N_{80\%} - N_i\right) \quad ,$$

$$N_{i+1} = N_{80\%} = N_i$$

where N_{i+1} и N_i The respective nearest larger and smaller consecutive members of the variation sequence relative to the obtained number N=80%;

T_i - the resource of the object corresponding to the consecutive member in the variation sequence;

T_{i+1} - The resource of the object corresponding to the consecutive member in the variation sequence

Determining the 80% gamma resource of the forklift's hydraulic cylinder - in the case of a truncated sample

Initial information - hydraulic cylinder

Table 1

Failures, liters of primary fuel		Stopped during observation, liters of primary fuel	
1.	1 086	1.	24 282
2.	9 395	2.	27 942
3.	11 797	3.	29 409
4.	17 457	4.	30 120
5.	20 971	5.	31 170
6.	22 510	6.	35 156
7.	24 084	7.	37 090
8.		8.	41 010

- The utilization of the failed and stopped elements is organized in a descending order:

Table 2

Failures, liters of primary fuel		Stopped during observation, liters of primary fuel	
1.	1 086	8.	24 282
2.	9 395	9.	27 942
3.	11 797	10.	29 409
4.	17 457	11.	30 120
5.	20 971	12.	31 170
6.	22 510	13.	35 156
7.	24 084	14.	37 090
		15.	41 010

- the member of the variation sequence with the 80% gamma resource is determined,

$$N_{80\%} = \frac{15.80}{100} + 0{,}5 = 10{,}1$$

- determining of the 80% resource of the element,

$$T_{80\%} = 29409 - (29409 - 30120)(10{,}1 - 10) = 29480$$

liters fuel.

<u>*In the case of an unknown resource distribution law and multiple truncated samples* - when the observations of N elements are terminated, some of them have exhausted their resource at utilization</u> $t_1, \quad t_2, \quad \dots \quad t_n$. The other part remained elements in working condition with utilization $T_1, \quad T_2, \quad \dots \quad T_{N-n}$, where the utilizations of some elements that have not exhausted their resource can be greater than those of the elements that have exhausted their resource.

In this scenario, the determination of the 80% gamma resource is carried out in the following sequence:

- The utilization of the remaining elements in working condition is arranged in ascending order, $T_1 < T_2 < \quad \dots \quad < T_k$;

- The intervals of utilization are numbered as follows: 1st interval - from 0 to T1; 2nd interval - from T1 to T2; up to the k-th interval - from Tk-1 to Tk;

- q_1- represents the number of elements for which the observation was terminated at utilization T_1; q_2- represents the number of elements for which the observation was terminated at utilization T_2; and $q_к$- represents the number of elements for which the observation was terminated at utilization $T_к$;

- n_1 represents the number of elements that have exhausted their resource in the first utilization interval (0 . . . T_1); n_2 epresents the number of elements that have exhausted their resource in the second utilization interval (T_1 . . . T_2); and $n_к$ epresents the number of elements that have exhausted their resource in the k-th utilization interval ($T_{к-1}$. . . $T_к$);

- N_1 represents the number of elements that continue operating after utilization T_1; N_2 represents the number of elements that continue operating after utilization T_2; and $N_к$ epresents the number of elements that continue operating after utilization $T_к$;

In accordance with the adopted notations, we determine the number of operational elements after each utilization interval:

$$N_1 = N - n_1 - q_1 \quad ;$$

$$N_2 = N_1 - n_2 - q_2 \quad ;$$

. . . .

$$N_k = N_{k-1} - n_k - q_k \quad ;$$

$$N_k = n_{k+1} \quad ;$$

$$n = n_1 + n_2 + \dots + n_{k+1} \quad ;$$

- probabilities of failure-free operation $P(t_i)$ for the failed elements at utilizations: $t_1, \quad t_2, \quad \dots \quad t_n$ are determined using the following formulas:

$$P(t_1) = 1 - \delta_1 \quad ;$$

$$P(t_2) = P(t_1) - \delta_2 \quad ;$$

. . . . .

$$P(t_n) = P(t_{n-1}) - \delta_n \quad ;$$

The value of δ_1 in the previous formula with $t_1 < T_1$, is determined by,

$$\delta_1 = (N+1)^{-1} \quad .$$

If there are utilizations of non-failed elements t_{i-1} *and* t_i (remaining in working condition) between the utilizations , and the maximum of those utilizations is denoted as Ti , then

$$\delta_1 = \frac{P(t_{i-1})}{N_i} \quad ,$$

where N_i e the number of elements remaining in working condition after the utilization T_i .

After calculating the values of δ_i for all utilizations t_i and T_i , including both failed and non-failed elements, we determine the failure probabilities $P(t_1)$ and $P(T_1)$. We find two adjacent utilizations (denoted as R_{i-1} and R_1) that satisfy the condition $P(R_{i-1}) > 0{,}8$ and $P(R_i) < 0{,}8$, and then we calculate the 80% gamma resource using the interpolation formula.

$$T_{80\%} = R_{i-1} + \left(R_i - R_{i-1}\right)\frac{P(R_{i-1} - 0{,}8)}{P(R_{i-1}) - P(R_i)} \quad .$$

To determine the 80% gamma resource of the engine cylinder head, considering multiple truncated samples

Initial information - engine cylinder head

Table 3

Failures, liters of primary fuel				Stopped during observation, liters of primary fuel					
1.	10 460	10.	24 670	1.	15 515	10.	22 850	19.	27 150
2.	11 153	11.	26 735	2.	15 571	11.	23 552	20.	27 303
3.	11 362	12.	34 330	3.	20 514	12.	23 915	21.	27 510
4.	12 016	13.	34 610	4.	21 023	13.	25 393	22.	29 291
5.	12 810			5.	21 481	14.	25 480	23.	30 005
6.	13 642			6.	21 841	15.	25 531	24.	30 669
7.	13850			7.	22 000	16.	25 624	25.	32 630
8.	14 119			8.	22 133	17.	25 724	26.	36 800
9.	23 606			9.	22 715	18.	26 909		

- determination of the number of elements in the individual intervals of the production:

Table 4

N_1=39 - 8 - 0 =31	N_{10}=23 - 0 - 1 =22	N_{19}=12 - 1 - 1 =10
N_2=31 - 0 - 1 =30	N_{11}=22- 0 - 1 =21	N_{20}=10 - 0 - 1 =9
N_3=30 - 0 - 1 =29	N_{12}=21 - 1 - 1 =19	N_{21}=9 - 0 - 1 = 8
N_4=29 - 0 - 1 =28	N_{13}=19 - 1 - 1 =17	N_{22}=8 - 0 - 1 = 7
N_5=28 - 0 - 1 =27	N_{14}=17 - 0 - 1 =16	N_{23}=7 - 0 - 1 = 6
N_6=27 - 0 - 1 =26	N_{15}=16 - 0 - 1 =15	N_{24}=6 - 0 - 1 = 5
N_7=26 - 0 - 1 =25	N_{16}=15 - 0 - 1 =14	N_{25}=5 - 0 - 1 = 4
N_8=25 - 0 - 1 =24	N_{17}=14 - 0 - 1 =13	N_{26}=4 - 2 - 1 = 1
N_9=24 - 0 - 1 =23	N_{18}=13 - 0 - 1 =12	

- determination the probability of trouble-free operation during production "T_1" of the elements stopped during observation

P(15515) = (39-8) / 39 = 0,8

P(15571) = 0,8 . (30-0) /30 = 0,8

Analogous

P(26514) = P(21023) = P(21481) = P(21841) = P(22000) = P(22130) = P(22715) = P(22850) = P(23522) = 0,8

P(23915) = 0,8. (22-1) :22 = 0,764

P(25393) = 0,764 . (19-1) : 19 = 0,723

P(25480) = P(25531) = P(25624) = P(25724) = P(26409) = 0,723

P(27303) = 0,723 . (13-1) : 13 = 0,668

P(27150) = P(27510) = P(29241) = P(30005) = P(30669) = P(32630) = 0,668

P(36800) = 0,668 . (15-2) : 5 = 0,441

- determining the probability of failure-free operation of the failed elements:

$\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8$ = 1 / (39+1) = 0,025

P(10460) = 1 - 0,025 = 0,975

P(11153) = 0,975 - 0,025 = 0,975

P(11632) = 0,950 - 0,025 = 0,925

P(12016) = 0,925 - 0,025 = 0,900

P(12810) = 0,900 - 0,025 = 0,875

P(13642) = 0,875 - 0,025 = 0,850

P(13950) = 0,850 - 0,025 = 0,825

P(14119) = 0,825 - 0,025 = 0,800

δ_9 = 0,80 / (21+1) = 0,0364

δ_{10} = 0,764 / (19+1) = 0,038

δ_{11} = 0,726 / (12+1) = 0,0558

$\delta_{12} = \delta_{13}$ = 0,670 : (5+1) = 0,112

P(23602) = 0,800 - 0,0364 = 0,764

P(24670) = 0,764 - 0,038 = 0,726

P(34330) = 0,670 - 0,112 = 0,558

P(34610) = 0,558 - 0,112 = 0,446

P(26735) = 0,726 - 0,0558 = 0,670

The results obtained indicate that:

P(14119 ÷23552) ≥ 0,8 > P(23602)

$$T_{80\%} = 18820 + (23602 - 18820)\frac{(0{,}8 - 0{,}8)}{(0{,}8 - 0{,}764)} = 18820 \quad l$$

- fuel

80% - gamma resource of the main components and assemblies of forklifts

Table 5

№	Components and Assemblies	80% Gamma Resource	№	Components and Assemblies	80% Gamma Resource
1.	Engine	13 171	12.	Voltage Regulator	7 204
2.	Cylinder Head	18 820	13.	Starter	14 073
3.	Nozzle	7 742	14.	Hydraulic Pump.	17 014
4.	Fuel Pump	19 835	15.	Distributor	22 198
5.	Priming Pump	17 637	16.	Hydraulic Cylinder	29 480
6.	Oil Pump	29 560	17.	Steering Axle	19 498
7.	Water Pump	10 402	18.	Drive Axle	19 496
8.	Radiator	23 410	19.	Wheel Set	9 016
9.	Clutch	11 847	20.	Lifting Device	17 889
10.	Gearbox	14 368	21.	Battery	8 482
11.	Generator	12 250			

Conclusions

A methodological approach for determining the 80% gamma resource of forklift components has been proposed, considering both known and unknown resource distribution laws, as well as truncated and multiple-truncated sampling.

The 80% gamma resource has been calculated for the main components of forklifts. The obtained results can be used for planning the needs for spare parts to maintain the operational readiness of forklifts.

References

1. Tasev G., M. Mihov, Sv. Madzhov, Theoretical Foundations of Reliability - Avangard Prima Publishing, Sofia, 2022, p. 554.

2. Mihov M., Reliability of Machinery in Agriculture - Avangard Prima Publishing, Sofia, 2012, p. 178.

3. Tasev G., Methods for Restoring Worn-Out Parts - Sofia, 2009, p. 254.

4. Mihov M., Repair of Agricultural Machinery - Monograph, Avangard Prima Publishing, Sofia, 2019, p. 153.

5. Davchev Zh., M. Mihov, G. Tasev, Methodology for Testing Agricultural Machinery - Avangard Prima Publishing, Sofia, 2021, p. 302.