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Reliability Analysis of Combine Harvesters

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ABSTRACT: The estimation of required total operational width of combine harvesters beforehand, especially for relatively big farms, is so important in terms of both the timely and possible least cost operation. Determination of required total operational width is a little bit complicate due to the difficulties in estimation of lost time resulted from unplanned breakdowns.

In the context of this study, reliability analyses of 14 combine harvesters with same made and model were made based on the breakdown records which contain time between failures. The historical data of time between failures were modeled according to Weibull Distribution with three parameters. A developed software, namely WEPTIBFES v 2.0 was used in parameter estimation. Additionally, the module of Monte-Carlo simulation was added into software to simulate the time between failures.

As a result of the study, totally 2470 data from 14 combine harvesters for last 10 years were evaluated. The estimated time between failures were calculated for given sub-systems of combine harvester. Weibull distribution parameters, the estimation statistics of β that defines the shape of distribution were determined. Additionally, and the result of validation tests were performed according to Kolmogorov-Smirnov test procedure. The lowest and the highest estimated time between failure values for cutting bar/feeding mechanism and components of control system were 82.16 and 234.74 hours respectively, while actual values were 88.2 and 254.2 hours.

Key words: Combine harvester, grain harvesting, reliability, time between failures

Biçerdöverlerde Güvenilirlik Analizi

Özet: Özellikle büyük işletmelerde tahıl hasadına başlanmadan önce, zamanında ve en az kayıpla hasadın tamamlanabilmesi için gerekli olan toplam biçerdöver iş genişliğinin tahmin edilebilmesi oldukça önemlidir. Gerekli toplam iş genişliğinin doğru bir şekilde belirlenmesi, arızalanmalar nedeniyle oluşacak zaman kayıplarının tahmin edilmesindeki güçlük nedeniyle karmaşık bir süreçtir. Bu çalışma kapsamında, aynı marka model 14 adet biçerdöverin arıza kayıtlarına dayalı olarak arızalar arası süre değerleri üzerinden güvenilirlik analizleri yapılmıştır. Arızalanmalar arası süre değerleri üç parametreli Weibull dağılımına göre modellenmiştir. Modellemenin yapılabilmesi için verilerin işlendiği, WEPTIBFES v 2.0 yazılımı geliştirilmiştir. Aynı yazılım içerisinde verileri kullanarak arızalanmalar arası sürenin tahmin edilebilmesine olanak veren Monte-Carlo simülasyon modülü de bulunmaktadır.

Çalışma sonucunda, 14 biçerdövere ait 10 yıllık toplam 2470 veri değerlendirilmiş, biçerdöver alt sistemlerine göre arızalanmalar arası süre değerleri tahmin edilmiştir. Belirlenen biçerdöver alt sistemleri için WEIBULL dağılımı parametreleri ayrıca dağılımın şeklini belirleyen β parametresine ilişkin istatistikler ve geçerlilik testi sonuçları verilmiştir. Buna göre; en küçük ve en büyük arızalanmalar arası tahmini süre değerlerinin kesme tablası/besleme düzeni ve kontrol sistemi elemanları için sırasıyla 82.16 ve 234.74 saat olduğu belirlenmiştir. Bu alt sistemler için gerçek arızalanmalar arası süre değerleri ise 88.2 ve 254.2 saat olarak hesaplanmıştır.

Anahtar Kelimeler: Biçerdöver, hasat, güvenilirlik, arızalar arası süre

INTRODUCTION

In order that agricultural production may be completed in time, selection of agricultural machines with proper capacity is the most important decision among those related to agricultural machines operation. Especially for agricultural operations like harvesting, the machine that would provide completion of works in the most convenient period is essential for estimation of work span value and operational economics. Whereas harvesting of grains may vary according to the type of crop and place of cultivation, it has to be completed in a certain period to prevent harvesting losses and prepare the field for the second crop (Say, 2001). It is impossible to use all of this period, defined as the optimum harvesting time, for harvesting due to climatic conditions. Therefore, as well as knowing about the optimum harvesting period, ratio of workable days must also be estimated through statistical analyses of multiyear climatic data. Another factor that is effective on required work span is the machine reliability value that is not considered in calculation of field efficiency (Hunt, 1983). It is inevitable to exceed the optimum harvesting period during active harvesting season and have product and income losses due to unforeseeable breakdowns. Therefore, advance prediction of harvester breakdowns is essential in estimation of work span that can provide completion of harvest within the optimum period. Prediction of reliability or operational availability of complex self-moving machines like harvesters is a process that requires statistical calculations. Facts like inability to define breakdowns properly, inability to determine environmental and working conditions accurately, and not knowing the active working period makes the process more complex (Tufts, 1985). Considering the above mentioned factors, number and characteristics of the breakdowns must be defined and intervals between consecutive breakdowns must be observed. Besides, in order to repair the breakdown that occurs during work in the field, effects of required time parameters on machine’s working compatibility must be examined. There is very limited number of publications about agricultural machines in the literature.

Kumar and Gross (1977) collected breakdown records from enterprises that use same brand and model of rice harvesting machines of 1 to 5 ages. WEIBULL distribution was used in modelling of failure rate of three different sub-systems. Intervals between breakdowns calculated by defined WEIBULL distribution parameters and real field data were compared and the results came out to be consistent.

Ward *et al.* (1985) defined repair costs and reliability values of silage mechanisation system under working conditions. Accordingly, data were collected from 145 machines of 4 different types making up the silage mechanisation system. As well as data like the number of breakdowns and repair time, data like total working hours, total harvested area, machine age and accumulated use hours were also analysed. Results of the study showed that for each machine type, repair costs were higher than the values defined in former studies. Besides, self-propelled harvesting machines (150 breakdowns/1000 ha) came out to be more reliable compared to trailer type harvesting machines (250 breakdowns /1000 ha).

Bohm (1993) realised a research study over breakdown records of 18 different tractor models to find out number of breakdowns in one tractor, number of breakdowns per 1000 working hours, and repair costs in both cases. It was found out that yearly average working time of the tractors was 391 hours, 6.3 breakdowns occurred in average and total average repair time was 5.40 days. Besides, it was emphasised that frequency of breakdowns is directly proportional to the age of the machine.

In their study, Say and Işık (1997) considered the parameters and methods used to define reliability, and the opportunities to make use of these during the planning stage. Within this study, failure rate occurring in a group of seeding machines working in one seeding season and operational availability values were calculated. As a result, reliability of 4 combined grain seeding machines working in one seeding season came out to be varying between 0.78 and 0.99. Furthermore, considering that these machines working at the same time constitute a machinery system, an equation to be used in calculated of system reliability was developed.

Laine and Jarvenpaa (1998) executed a questionnaire covering 500 enterprises to find out the reliability and actual maintenance costs of tractors and harvesters in Finland. Average tractor engine power came out as 74 kW, average tractor age came out as 8.2 years and average yearly working time came out as 618 hours. Average harvester age was 9.9 years, average yearly use was 121 hours and 105 ha/years. According to the results of this study, breakdown frequency (number yearly breakdowns per machine) came out as varying between 0.6 to 1.2 for tractors of 1-15 years and 0.6 to 2.1 for harvesters that were used between 500 to 2000 hours in cumulative.

In this study, ten-year breakdown records of 14 harvesters of the same brand and model used in grain harvesting under the same operational conditions were examined, and intervals between breakdowns were modelled using Weibull distribution.

MATERIAL and METHOD

Material

Harvesters used in examination of breakdown data are CLAAS brand Dominator 88 S type harvesters used in Ceylanpınar Agricultural Farm. Harvesters are 5 straw walker types and harvesting width is 5.1 meters. Threshing drum speed of harvesters with 110kW engine power can be adjusted between 650-1500 min^{-1}. Breakdown data of the 14 harvesters with ten-year breakdown records among the 70 harvesters owned by the enterprise were gathered from the records of the enterprise to be used in calculations.

Time between failures data were processed in the developed Weptibfes v 2.0 software. All of the harvesters having average yearly working hours of 472±16.1 from 1989, in which they were purchased, to 1999 had been used in harvesting of wheat and lentils cultivated in irrigated and dry conditions. Average cumulative working hours within the above mentioned period is 5047±67.35.

Method

Reliability of a machine is its probability to perform its function within a defined period with certain restrictions under certain conditions (ASAE, 1994; Billinton and Allan, 1992). Machine's operational availability is the proportional expression of reliability; therefore it is the period in which the machine can perform its function without any breakdowns (Tufts, 1985). Reliability of any equipment is related to frequency of failures and frequency of failures is expressed by the *"mean time between failures"*.

The parameter defining a machine's reliability is the failure rate (λ). This value is the characteristic of breakdown occurrence frequency. Failure rate is equal to the reciprocal of the mean time between failures (MTBF) defined in hours (Calobro, 1962; Tufts, 1985; Billinton and Allan, 1992). Therefore;

$$\lambda = \frac{1}{MTBF} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[1]$$

The main issue considered under reliability theory is to define according to which statistical distribution breakdowns occur, that means defining of the occurrence characteristic of failure probability. Failure probability is defined by a probability distribution indicating ratio of breakdowns versus time. Therefore, failure rate is deterministic in selection of statistical distribution. Distribution to be selected is the intensity function of breakdown probability that occurs depending on a continuous chance variable.

Breakdown is a situation that decreases work efficiency of any equipment and it is examined under 3 different categories during physical use of the equipment (Kumar and Gross, 1977; Billinton and Allon, 1987). These are, breakdowns that occur in the early years of use, breakdowns that occur during useful life period machine and breakdowns that occur in the wearout period of the machine (Figure 1).

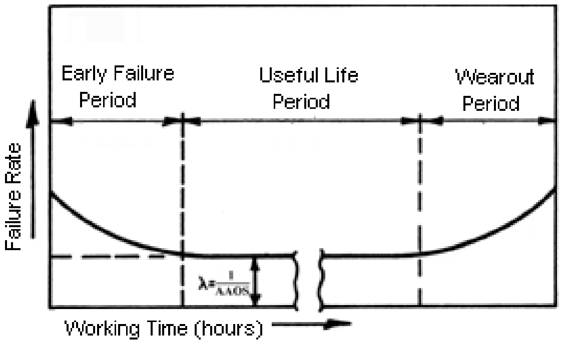


Figure 1. Sample reliability curve (bathtub curve)

WEIBULL distribution, which is a multi parameter distribution, is a very flexible statistical distribution that increases or remains stable as the parameter values change and used in defining of breakdown ratio values (Weibull, 1951; Tufts, 1985). Intensity function of WEIBULL breakdown probability can be formulised as below (Billinton and Allan, 1992):

$$f(x)= \begin{cases} \dfrac{\beta(x-\gamma)^{\beta-1}}{\alpha} e^{\frac{-\left[(x-\gamma)^{\beta}\right]}{\alpha}} & \text{when x>y} \\ & \ldots.. \quad \ldots\ldots.[2] \\ 0 & \text{in other conditions} \end{cases}$$

In the equality, α is scale parameter, β is function shape parameter or WEIBULL slope, γ is location parameter or the limit of bottom lifespan. Shape parameter (β) defines the general shape of distribution. In other words, it is deterministic on whether the model has an increasing, stable or decreasing failure rate.

There is a wide variety of methods to be used in estimation of WEIBULL parameters. Least squares method has been used in the study. The equality after natural logarithmic conversions is as follows:

$$y = \ln\ln\left[\frac{1}{1-F(x)}\right];\quad \mathrm{m} = \beta;\ \mathrm{c} = -\ln\alpha;\ \mathrm{x} = \ln\mathrm{x} \text{ ....[3]}$$

A linear graphic is obtained if $\ln\ln\left[\frac{1}{1-F(x)}\right]$ is placed in the ordinate and **lnx** is placed in the abscissa after converting WEIBULL cumulative distribution function into a linear equality with a certain slope. After this stage, ***α*** and ***β*** parameters may be estimated by regression analysis depending on least squares method. It has been tested by "Kolmogorov – Smirnov Test" whether distribution used for modelling of the time between failures represent real conditions within acceptable limits.

After estimation of WEIBULL parameters, it must be decided on how this distribution is going to be used for planning in the farm. Monte-Carlo simulation method is used for this purpose in reliability studies (Kumar and Gross, 1977). Through Monte-Carlo simulation method, random time between failures are obtained from a probability distribution whose intensity function is **f(x)**. For this, **t** must be solved in the equality below.

When the equality

$$y = \int_0^t \frac{\beta x^{\beta-1}}{\alpha} e^{-\frac{x^\beta}{\alpha}}\, dx \text{ ....[4]}$$

is integrated, following equation is obtained:

$$y = 1 - e^{-\frac{t^\beta}{\alpha}} \Rightarrow 1 - y = e^{-\frac{t^\beta}{\alpha}} \text{ ....[5]}$$

Because **y** value is coincidentally produced between 0 and 1, **1-y** is also a coincidental value within the same interval. When equation number [5] is solved for **t,** either of the following is obtained:

$$-\frac{t^\beta}{\alpha} = -\ln(1-y) \quad \text{or} \quad \text{......................................[6]}$$

$$t = [\alpha(-\ln(1-y))]^{1/\beta} \text{ ....[7]}$$

t value represents the time between failures. When modelling the time between failures, the combine harvester has been classified into 5 sub systems performing different function. These systems are: 1) Cutter bar and feeding system, 2) Control system elements (hydraulic, electronic systems), 3) General motion transmission elements, 4) Threshing and separating system, 5) Cleaning and unloading system.

At the end of modelling, value of α, β and standard deviation of β for each sub system, and the estimated average interval between breakdowns were calculated. Besides, results of Monte-Carlo simulation made according to Weibull parameter values for harvester sub systems were given as screen shots in the research findings section.

RESEARCH FINDINGS

General Results Related to the Breakdowns

Number of breakdowns and proportional distribution of these breakdowns for 14 harvesters and their sub systems for ten-year harvest period are given in Table 1.

Table 1. Number of breakdowns and their shares among total number of breakdowns

Sub System	Number of Total Breakdowns*	Ratio %
Cutter bar and feeding mechanism (**CFM**)	**865** (180) feeding elev. (505) cutter bar (180) rev. reel-feeder	35.0
Control System Elements (**CSE**)	**309** (74) fuel system (141) hydraulic components (94) engine	12.5
General Motion Transmission Elements (**GMTE**)	**401** (284) main power belt (80) rack pulley ball (37) main pulley bolt	16.2
Threshing and Separating System (**TSS**)	**436** (153) beater – concace (87) splitter (196) straw walker	17.7
Cleaning and Unloading System (**CUS**)	**459** (328) Sieve system (60) Unloading auger (71) Cleaning fan	18.6
Total	**2470**	100

*: Breakdowns according to sub systems are given in a general classification, but detailed definition of defective parts are not given in the table.

As seen in the table, 2470 breakdowns were processed according to sub systems in the Weptibfes v 2.0 software. The mean time between failures for the sub systems are calculated **88.2**±1.1, **254.2**±11.2, **192.6**±5.3, **177.5**±4.7, **168.2**±3.95 hours for CFM, CSE, GMTE, TSS, CUS respectively.

Weibull Distribution Parameters

Weibull parameter values obtained by processing of time between failures of sub systems in developed **WEPTIBFES 2.0** software are given in Table 2. In Table 3, standard deviation for parameter ***β,*** confidence limits and the estimated mean time between failures (*MTBF*) are displayed.

Table 2. Weibull Distribution Parameters

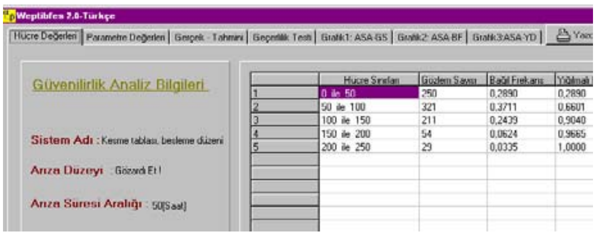
Sub System	α	β
CFM	8812.38	2.01
CSE	18 798 436	3.01
GMTE	32 017 095	3.24
TSS	2 024 588	2.73
CUS	20033	1.91

Table 3. Evaluation of parameter *β*

Sub System	Standard Deviation	Reliability Interval	Estimated AIBB
CFM	0.2691	1.48-2.54	82.16
CSE	0.1229	2.77-3.25	234.74
GMTE	0.1120	3.02-3.46	182.58
TSS	0.1453	2.45-3.02	180.68
CUS	0.1467	1.63-2.20	157.58

WEPTIBFES v 2.0 Screen Shots

After Weibull parameters estimation from the time between failures, parameter values calculated for each sub-system were transferred to the Monte-Carlo simulation process included in the Weptibfes v 2.0 software as a module. Relative and cumulative function values and graphical display of cumulative distribution function and results of Monte-Carlo simulation related to observation values according to real and theoretical time between failures for each sub-systems of harvesters are given in the figures below.



Güvenilirlik Analiz Bilgileri

Sistem Adı : Kesme tablası, besleme düzeni

Arıza Düzeyi : Gözardı Et !

Arıza Süresi Aralığı : 50[Saat]

	Hücre Sınıfları	Gözlem Sayısı	Bağıl Frekans	Yığılmalı
1	0 ile 50	250	0,2890	0,2890
2	50 ile 100	321	0,3711	0,6601
3	100 ile 150	211	0,2439	0,9040
4	150 ile 200	54	0,0624	0,9665
5	200 ile 250	29	0,0335	1,0000

Figure 2. Relative and cumulative frequency values related to time between failures for cutter bar and feeding mechanism.

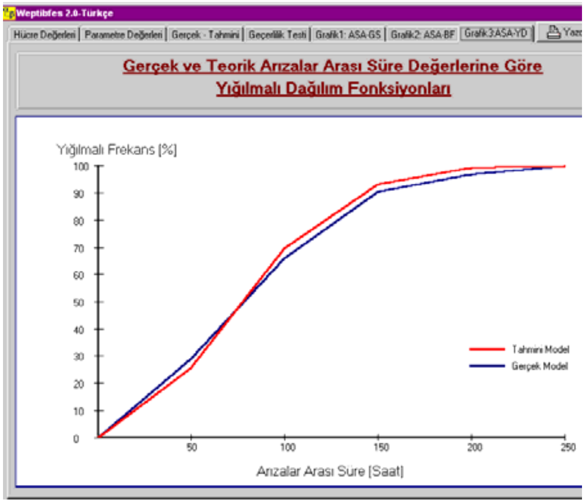
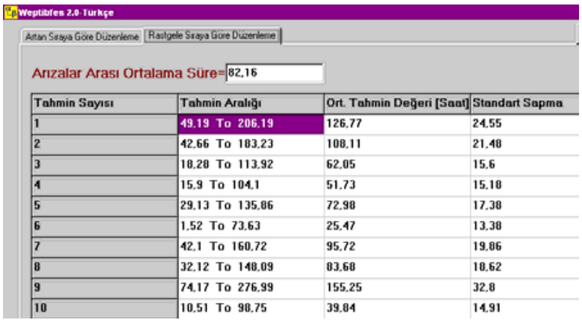


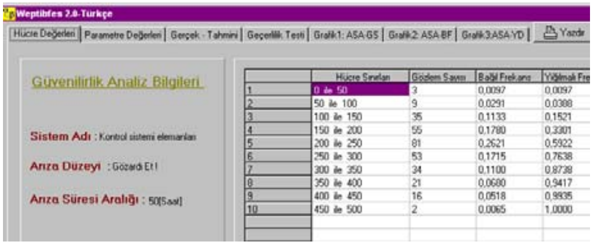
Figure 3. Graphical display of cumulative distribution function according to real and theoretical time between failures for cutter bar and feeding mechanism (*α=0.01*; $d_{calculation}$ (0.0351)<d_{table} (0.0554)).



Arızalar Arası Ortalama Süre= 82,16

Tahmin Sayısı	Tahmin Aralığı	Ort. Tahmin Değeri [Saat]	Standart Sapma
1	49,19 To 206,19	126,77	24,55
2	42,66 To 183,23	108,11	21,48
3	10,28 To 113,92	62,05	15,6
4	15,9 To 104,1	51,73	15,18
5	29,13 To 135,86	72,98	17,38
6	1,52 To 73,63	25,47	13,38
7	42,1 To 160,72	95,72	19,86
8	32,12 To 148,09	83,68	18,62
9	74,17 To 276,99	155,25	32,8
10	10,51 To 98,75	39,84	14,91

Figure 4. Results Screen for Monte-Carlo simulation according to WEIBULL distribution parameters calculated by failure data of cutter bar and feeding mechanism.



Güvenilirlik Analiz Bilgileri

Sistem Adı : Kontrol sistemi elemanları

Arıza Düzeyi : Gözardı Et!

Arıza Süresi Aralığı : 50[Saat]

	Hücre Sınıfları	Gözlem Sayısı	Bağıl Frekans	Yığılmalı Fre
1	0 ile 50	3	0,0097	0,0097
2	50 ile 100	9	0,0291	0,0388
3	100 ile 150	35	0,1133	0,1521
4	150 ile 200	55	0,1780	0,3301
5	200 ile 250	81	0,2621	0,5922
6	250 ile 300	53	0,1715	0,7638
7	300 ile 350	34	0,1100	0,8738
8	350 ile 400	21	0,0680	0,9417
9	400 ile 450	16	0,0518	0,9935
10	450 ile 500	2	0,0065	1,0000

Figure 5. Relative and cumulative frequency values related to time between failures for Control System Elements.

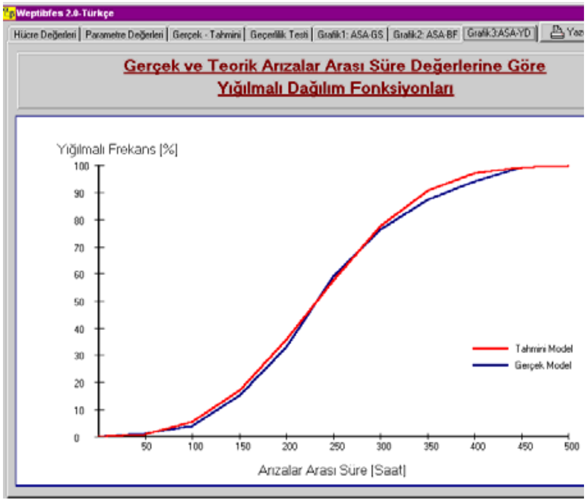
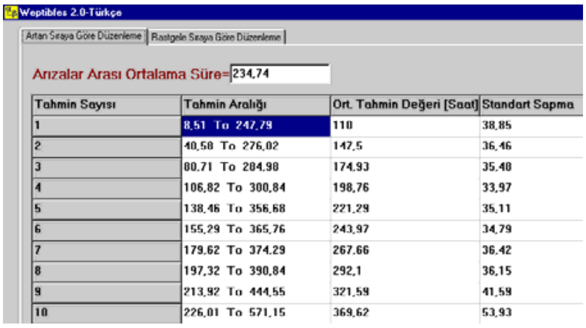


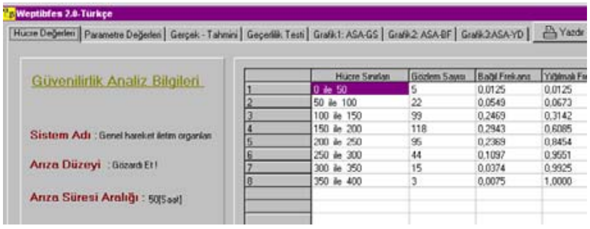
Figure 6. Graphical display of cumulative distribution function according to real and theoretical time between failures for Control System Elements ($\alpha=0.01$; $d_{calculation}$ (0.0322)<d_{table} (0.0927)).



Arızalar Arası Ortalama Süre=234,74

Tahmin Sayısı	Tahmin Aralığı	Ort. Tahmin Değeri [Saat]	Standart Sapma
1	8,51 To 247,79	110	38,85
2	40,58 To 276,02	147,5	36,46
3	80.71 To 284.98	174,93	35.48
4	106,82 To 300,84	198,76	33,97
5	138,46 To 356,68	221,29	35,11
6	155,29 To 365,76	243,97	34,79
7	179.62 To 374.29	267.66	36.42
8	197,32 To 390,84	292,1	36,15
9	213,92 To 444,55	321,59	41,59
10	226,01 To 571,15	369,62	53,93

Figure 7. Results Screen for Monte-Carlo simulation according to WEIBULL distribution parameters calculated by failure data of Control System Elements.



Güvenilirlik Analiz Bilgileri

Sistem Adı : Genel hareket iletim organları

Arıza Düzeyi : Gözardı Et!

Arıza Süresi Aralığı : 50[Saat]

	Hücre Sınıfları	Gözlem Sayısı	Bağıl Frekans	Yığılmalı Fr
1	0 ile 50	5	0,0125	0,0125
2	50 ile 100	22	0,0549	0,0673
3	100 ile 150	99	0,2469	0,3142
4	150 ile 200	118	0,2943	0,6085
5	200 ile 250	95	0,2369	0,8454
6	250 ile 300	44	0,1097	0,9551
7	300 ile 350	15	0,0374	0,9925
8	350 ile 400	3	0,0075	1,0000

Figure 8. Relative and cumulative frequency values related to time between failures for General Motion Transmission Elements.

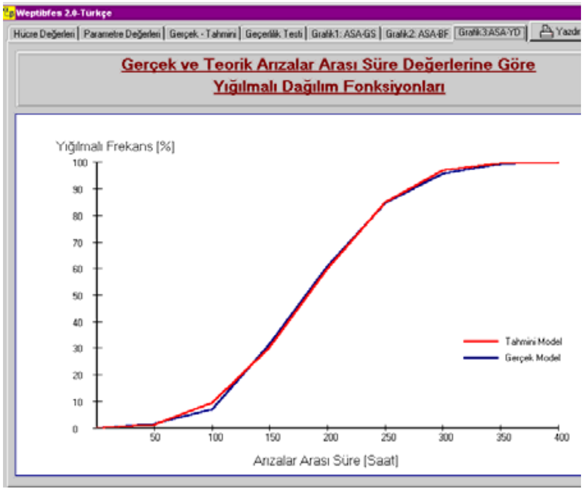
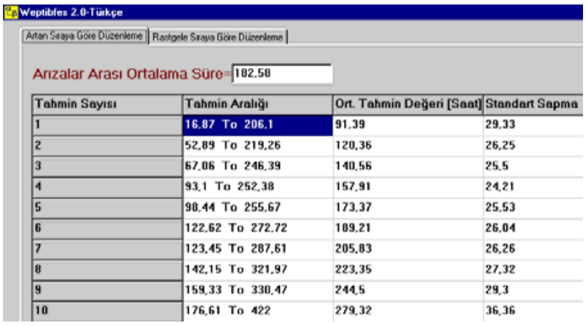


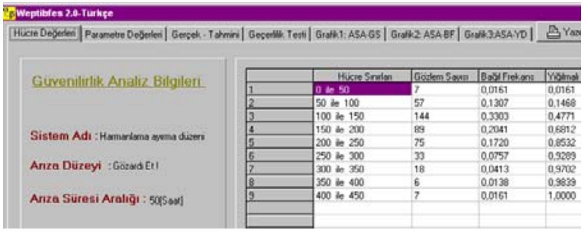
Figure 9. Graphical display of cumulative distribution function according to real and theoretical time between failures for General Motion Transmission Elements ($\alpha=0.01$; $d_{calculation}$ (0.0246)<d_{table} (0.0814)).



Arızalar Arası Ortalama Süre=182,58

Tahmin Sayısı	Tahmin Aralığı	Ort. Tahmin Değeri [Saat]	Standart Sapma
1	16,87 To 206,1	91,39	29,33
2	52,89 To 219,26	120,36	26,25
3	67,06 To 246,39	140,56	25,5
4	93,1 To 252,38	157,91	24,21
5	98,44 To 255,67	173,37	25,53
6	122,62 To 272,72	189,21	26,04
7	123,45 To 287,61	205,83	26,26
8	142,15 To 321,97	223,35	27,32
9	159,33 To 330,47	244,5	29,3
10	176,61 To 422	279,32	36,36

Figure 10. Results Screen for Monte-Carlo simulation according to WEIBULL distribution parameters calculated by failure data of General Motion Transmission Elements.



Güvenilirlik Analiz Bilgileri

Sistem Adı : Harmanlama ayırma düzeni

Arıza Düzeyi : Gözardı Et !

Arıza Süresi Aralığı : 50[Saat]

	Hücre Sınıfları	Gözlem Sayısı	Bağıl Frekans	Yığılmal
1	0 ile 50	7	0,0161	0,0161
2	50 ile 100	57	0,1307	0,1468
3	100 ile 150	144	0,3303	0,4771
4	150 ile 200	89	0,2041	0,6812
5	200 ile 250	75	0,1720	0,8532
6	250 ile 300	33	0,0757	0,9289
7	300 ile 350	18	0,0413	0,9702
8	350 ile 400	6	0,0138	0,9839
9	400 ile 450	7	0,0161	1,0000

Figure 11. Relative and cumulative frequency values related to time between failures for Threshing and Separating System.

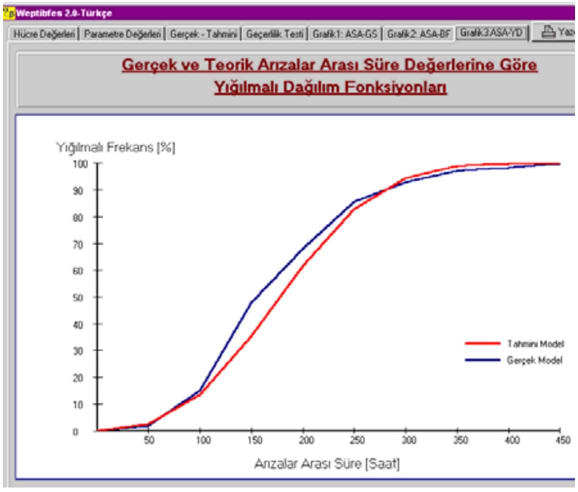
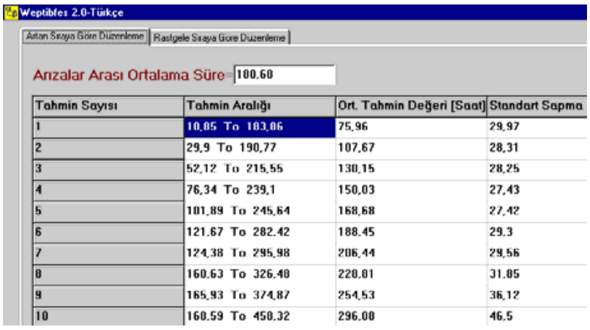


Figure 12. Graphical display of cumulative distribution function according to real and theoretical time between failures for Threshing and Separating System (*a=0.01*; $d_{calculation}$ (0.1241)>d_{table} (0.0781))



Arızalar Arası Ortalama Süre= 100.60

Tahmin Sayısı	Tahmin Aralığı	Ort. Tahmin Değeri [Saat]	Standart Sapma
1	10,05 To 103,06	75,96	29,97
2	29,9 To 190,77	107,67	28,31
3	52,12 To 215,55	130,15	28,25
4	76,34 To 239,1	150,03	27,43
5	101,89 To 245,64	168,68	27,42
6	121.67 To 282.42	188.45	29.3
7	124,38 To 295,98	206,44	29,56
8	160.63 To 326.40	220.01	31.05
9	165,93 To 374,87	254,53	36,12
10	160.59 To 450.32	296.00	46.5

Figure 13. Results Screen for Monte-Carlo simulation according to WEIBULL distribution parameters calculated by failure data of Threshing and Separating System.

Güvenilirlik Analiz Bilgileri

Sistem Adı : Temizleme boşaltma düzeni

Arıza Düzeyi : Gözardı Et !

Arıza Süresi Aralığı : 50[Saat]

	Hücre Sınıfları	Gözlem Sayısı	Bağıl Frekans	Yığılmalı F
1	0 ile 50	43	0,0937	0,0937
2	50 ile 100	97	0,2113	0,3050
3	100 ile 150	99	0,2157	0,5207
4	150 ile 200	62	0,1351	0,6558
5	200 ile 250	66	0,1438	0,7996
6	250 ile 300	39	0,0850	0,8845
7	300 ile 350	35	0,0763	0,9608
8	350 ile 400	9	0,0196	0,9804
9	400 ile 450	9	0,0196	1,0000

Figure 14. Relative and cumulative frequency values related to time between failures for Cleaning and Unloading System.

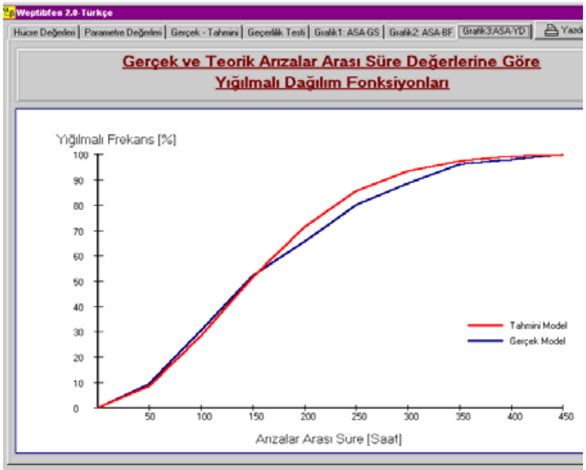
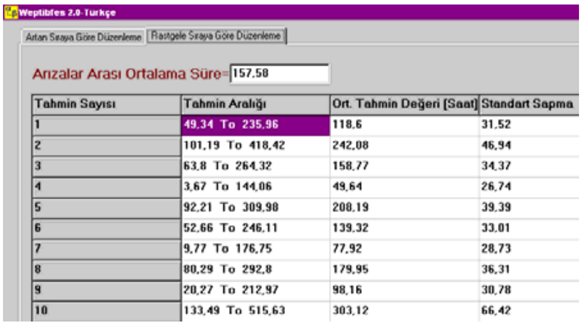


Figure 15. Graphical display of cumulative distribution function according to real and theoretical time between failures for Cleaning and Unloading System (*a=0.01*; $d_{calculation}$ (0.1241)>d_{table} (0.0781))



Arızalar Arası Ortalama Süre= 157,58

Tahmin Sayısı	Tahmin Aralığı	Ort. Tahmin Değeri [Saat]	Standart Sapma
1	49,34 To 235,96	118,6	31,52
2	101,19 To 418,42	242,08	46,94
3	63,8 To 264,32	158,77	34,37
4	3,67 To 144,06	49,64	26,74
5	92,21 To 309,98	208,19	39,39
6	52,66 To 246,11	139,32	33,01
7	9,77 To 176,75	77,92	28,73
8	80,29 To 292,8	179,95	36,31
9	20,27 To 212,97	98,16	30,78
10	133,49 To 515,63	303,12	66,42

Figure 16. Results Screen for Monte-Carlo simulation according to WEIBULL distribution parameters calculated by failure data of Cleaning and Unloading System.

According to results of validity test, time between failures in all sub-systems except threshing and separation sub-system came out to be consistent with WEIBULL distribution. Although it was determined by D-test (Kolmogorov-Smirnov test) that time between failures in threshing and separation sub-system components could not be explained by WEIBULL distribution, WEIBULL distribution can be used in estimation of mean time between failures in the farm within tolerable error limits.

DISCUSSION and CONCLUSION

Determination of time losses within daily working time planned by the farm managers for harvesting due to machinery breakdowns is very important for estimation of work span before the season. Harvest that cannot be completed in its optimum period causes crop losses and therefore time costs.

Estimated time between failures obtained in the research and calculated by simulations may guide farm managers about failure frequency of future harvest seasons. Besides, these values may be used for calculation of spare part stocks.

According to TUİK (Turkish Statistical Institute) (Anonymous, 2008), 7653 (*58.5%*) of the total 13084 registered harvesters used in 10^6 ha of grain fields as of 2008 are of age 11 or over. Furthermore, 3996 harvesters (*30.5%*) are above 21 years. This tells that in our country, in which grain harvesting is made through contracting mostly, harvesters used are quite old. This means that probability of frequent failures is high. In order to complete the harvest in the optimum harvest period, in which grain losses are minimal, and to suppress interruptions due to breakdowns to the extent possible, renewal of our harvester fleet in proper policies is very important for the country's economy, as well as estimation of fleet size before the season. Proper estimation of time between failures through statistical distributions like the Weibull distribution is only possible by using data from the machines used under similar conditions. For example, it is not possible to obtain correct results by analysing machine breakdown data collected from farms with different repair and maintenance policies, yearly working hours, harvested crops and working conditions. Furthermore, time spent for repair of the breakdown is as important as the frequency of breakdown for a farm. Time to repair may vary greatly from farm to farm. Modelling of repair time according to defective sub-system and defective component may be possible by using similar cumulative distribution functions for enterprises with a certain repair and maintenance policy.

There has been a limited number of similar researches and this research is different in having collected breakdown data of relatively homogeneous operational conditions.

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