ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20161103131425
Original scientific paper

The System of Tractors Operation in the Aspect of Services Provided by an Authorised Service Station

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Abstract: This article presents problems connected with the system of operation of agricultural tractors. The aim of this article was to determine the level of reliability of used agricultural vehicles in the aspect of needs for technical services in the authorized service station. The quantitative structure of 6127 repairs carried out by an authorized service regarding 1731 tractor pieces sold to users by a distribution company has been described in a monthly arrangement. The analysis encompasses the arrangement of the number of technical services in a percentage array in the years 2003-2014. The data analysis shows that the trend line determined for post-warranty services has varied over a span of the analysed period. The analysed services had a large amplitude of random fluctuations. The acquired seasonal indexes values prove the cyclical changes of demand for servicing in subsequent months. The tendency in the behaviour of the users who own modern agricultural tractors, to more and more common use of authorised services when it comes to carrying out technical services of the operated equipment was confirmed.

Keywords: agricultural tractors; post-warranty repairs; reliability; technical service

1 INTRODUCTION

In order to facilitate animal and vegetable production, modern agriculture requires effective and efficient technical equipment of farms. East-Central European states' accession to the European Union initiated system activities connected with the modernisation of domestic agricultural production [1]. The development of the average age of machinery and equipment could be used as an indicator of the modernisation process and the picture of investment support in the industry. The analysis shows significant differences in the institutional sectors [2, 3]. Primarily, it was focused on changing the structure of farms in Poland and Latvia, concluding the agricultural reform in Lithuania and carrying out land privatization in Hungary and Czech Republic. The past decade of Polish presence in the EU structures and the previous ten years of integration processes were times of radical and deep changes. Thanks to the financial support from the EU funds, a deep restructuring of domestic agriculture and modernization of technical equipment of respective farms were executed in order to adapt the industry for the free market requirements. The wear of machines has a negative impact on their productivity in agriculture [4]. To meet the scheduling demands of dispatching the agricultural machinery to the reasonable farmlands, time-windows based temporal and spatial scheduling model for agricultural machinery resources was built, which serialized decision-making processes and got optimal solutions for each process [5]. During that period, in the territory of Poland and other countries from the East-Central Europe, the leading foreign concerns and domestic producers of the agricultural tractor and machine industry built the modern infrastructure that encompassed the logistically vast chain of authorised trade and service branches [6]. The free market standard is to provide professional technical service of products, encompassing inspections and repairs, by the general distributor and subordinate dealers [7]. In order to meet customers' expectations, each of the producers on the domestic market has a couple of dozens of company service stations at their disposal [8]. Parallel to this structure there is a vast chain of independent unauthorised workshops that provide technical services for the needs of local users [9]. The modern construction solutions and control systems used in contemporary tractors and agricultural machines are the result of intensive research and development works and scientific research [10]. This is enabled, above all, by introducing electronic control systems and their wide application in different systems of the tractor [11, 12]. High technical level greatly reduces the amount of labour that the user can perform on his own. Instead, all these works are commissioned to the specialist service stations [13, 14].

Quality management and assurance systems, commonly included in modern production and construction processes, should, in theory, guarantee functionality and reliability of the tractors and machines during usage [15, 17]. The course of operations in the process of producing technical objects that is in accordance with the technological documentation should lead to creating products of expected quality and reliability. Despite undertaking activities that are consistent with the quality assurance system at respective stages of production process, some errors in material and execution of parts and units still might occur. If not properly identified and repaired or scrapped, they increase the probability of product malfunctioning. Tractors and working machines are complex objects, prone to various processes of technical condition deterioration during the usage period [18, 19]. The wear intensity of the units depends on their construction, but mainly on the operation conditions, which are rather tough for the tractors and agricultural machines. As an operation subsystem, the usage introduces the risk of exceeding allowed internal load for a given tractor or machine model, working in conditions of aggressive environment (dust, mineral and organic pollution), improper usage and undergoing service by significantly underqualified operators (considering the technical level of the product), which is a potential malfunction source in the usage process [20, 21]. Distribution is heavily supported by professional consultancy in the framework of selecting technical products according to clients' needs and requirements [7]. Education in the aspect of agricultural engineering is very important here, as well as carrying out proper user trainings by authorised dealer's right after the purchase in order to

provide the best performance of tractors and machines in the operation process [22, 23].

1.1 Materials and Methods

The research matter of this work was to determine the reliability level of agricultural tractors in use in the aspect of the demand for services restoring the fitness for use, provided by an authorised service station in the post-warranty period granted by the producer.

It has to be emphasised that agricultural tractors play a vital role in the process of mechanisation due to the fact that they are the tractive force behind transportation works and source of energy for driving the agricultural machines.

The data collected during research allowed to determine the correlation between the number of repairs of agricultural tractors carried out by the authorised service department and the number of vehicles sold to users by a distribution company in the serviced area. Over a span of 12 years the distributor, in accordance with the market needs, has logistically secured the whole operation system in the field of spare parts delivery and full service.

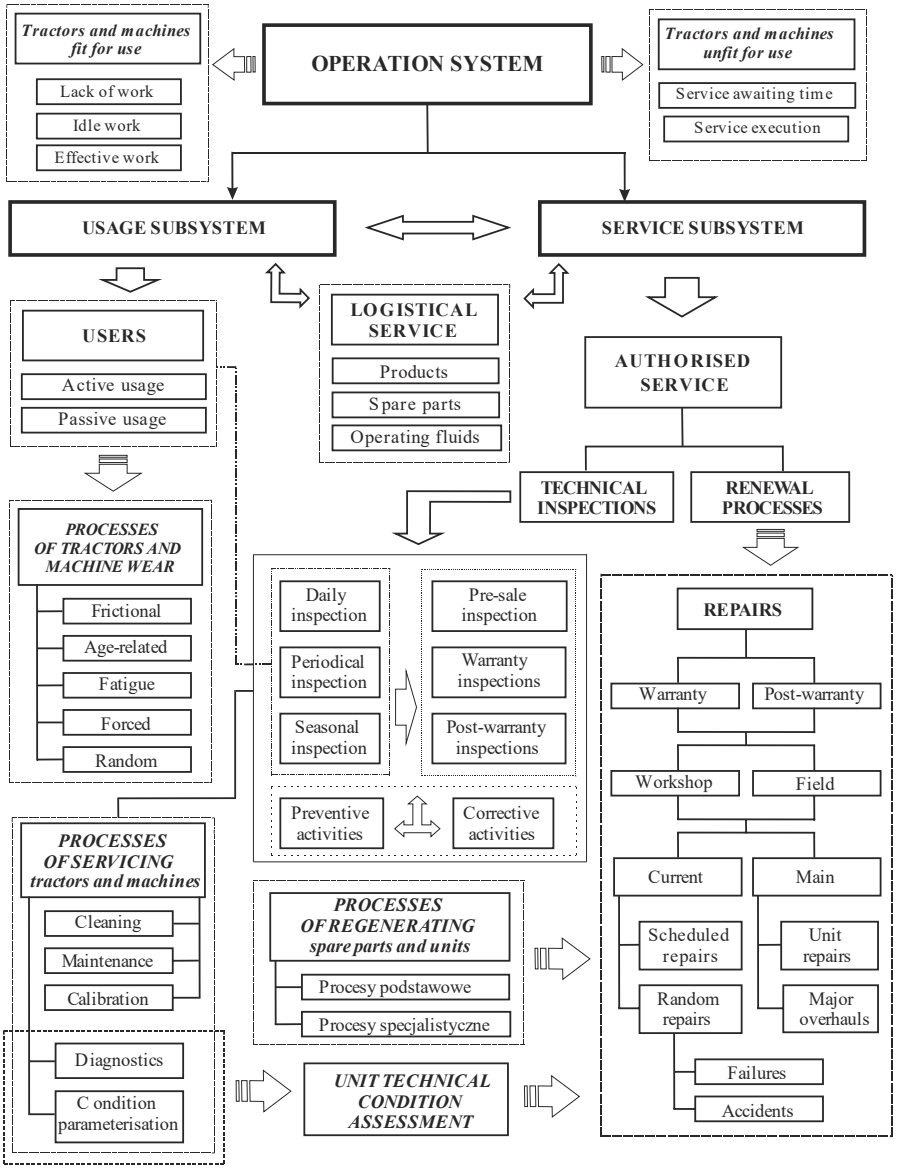

Figure 1 The structure of operation system in the field of the subsystems of usage and servicing of agricultural tractors and machines

The carried out research also allowed to design a structure of the system of tractor and agricultural machine operating in the field of usage subsystem and service subsystem, as presented in Fig. 1. There are cyclical relationships between the users and technical service in the operation system, which is a collection of purposeful organisational, technical and economical activities [24, 25]. The main component of the agricultural machine and vehicle operation system is the usage subsystem. Parallel to that subsystem, there is also a service subsystem that is functioning on the market. The usage system includes only objects that are fit for use. When they become unfit for use, they undergo the renewal process by the authorised service station. Logistical service in the operation system is currently regarded as a vital element of the process of supplying spare parts and operating fluids, oftentimes with the use of the method of outsourcing in transportation. The processes of changes of the technical condition i.e. physical wear and changes in settings, determine the technical inspections. Preventive activities are performed by users

through due diligence in carrying out daily, periodical and seasonal inspections and this results in further inspections in service stations [25, 26]. Proper activities in the usage system regard servicing in the field of maintaining cleanliness, maintenance and setting the work parameters that constitute a vital element that extends the efficiency period and prolongs the tractors and machines' fitness for use. On-board diagnostics, with the use of the Controller Area Network, will locate the malfunction and the service-bay diagnostics will assess the technical condition of individual units and componentry. It will also support renewal processes that restore the fitness for use [27]. The processes of renewing the fit for use of technical objects encompass various configuration of repairs that vary in terms of time, place and range of carried out works. Oftentimes, the previously refurbished parts and components are used for the purposes of servicing, which should reduce the costs of conducted works.

The refurbishment of agricultural tractors carried out by a service, creating a time series Y_t, was statistically analysed in order to determine the character of the analysed process. The multiplicative model of the elements of the time series was used in order to determine the trend value, random fluctuations and seasonal fluctuations [28, 29].

The value of the centre moving averages for subsequent months of the series is presented in the following equation:

$$\overline{y}_t^{(d)} = \frac{1}{d}\left(\frac{1}{2}y_{t-\frac{d}{2}} + \sum_{t-t_0}^{t+t_0} y_t + \frac{1}{2}y_{t+\frac{d}{2}}\right),\ t_0 = \frac{d}{2} - 1 \tag{1}$$

The value of seasonal indexes was determined in accordance with the following equation:

$$O_i = \frac{1}{c}\left[\sum_{t=1}^{c}\frac{y_{t_i}}{\overline{y}_{t_i}^{(d)}}\right]\cdot 100 WK^{(M)} \tag{2}$$

where: c - the number of periodic cycles; $WK^{(M)}$ - average multiplicative corrective ratio for achieving $\sum_{i=1}^{12} O_i = 1200.$

The average multiplicative corrective ratio is defined by the following equation:

$$WK^{(M)} = \frac{100\cdot d}{\frac{1}{c}\sum_{t=1}^{c}\frac{y_{t_i}}{\overline{y}_{t_i}^{(d)}}\cdot 100} \tag{3}$$

The value of random fluctuations for the multiplicative series is defined by the following equation:

$$y_{t(skor)}^{(M)} = \frac{y_t}{O_i}\cdot 100 \tag{4}$$

The trend line for the analysed time series was calculated using the 5-period weighted average in accordance with the following equation:

$$\hat{y}_t^{(M)} = \overline{y}_t^{(5)(M)} = \frac{1}{g}\sum_{t-2}^{t+2} y_{t(skor)}^{(M)}\cdot w_t \ \text{ for } [\boldsymbol{w}_t] = \begin{bmatrix}1\\2\\3\\2\\1\end{bmatrix} \tag{5}$$

Their graphic analysis of the impact of seasonal fluctuations on the arrangement of variables set was made by comparing them to an average level which amounts to 100% for seasonal indexes.

Pearson product-moment correlation coefficient (correlation coefficient from the sample) for a large set is defined by Eq. (6). It allows to assess the level of interrelations between the random variables X_t (the number of sold tractors) and Y_t (the number of post-warranty tractor repairs). The research encompassed the sample with the number of $t = 1, 2, \ldots, 144$ months in the years 2003-2014.

$$r_{xy} = \frac{\sum_{t=1}^{n}(x_t - \overline{x})\cdot(y_t - \overline{y})}{\sqrt{\sum_{t=1}^{n}(x_t - \overline{x})^2 \sum_{t=1}^{n}(y_t - \overline{y})^2}} \tag{6}$$

where: r_{xy} - correlation coefficient from the sample; y_t - the number of post-warranty repairs of agricultural tractors in a monthly arrangement; x_t - the number of sold agricultural tractors in a monthly arrangement.

$$\overline{x} = \frac{1}{n}\sum_{t=1}^{n} x_t \tag{7}$$

$$\overline{y} = \frac{1}{n}\sum_{t=1}^{n} y_t \tag{8}$$

The correlation coefficient from the sample has the value: $-1 \le r_{xy} \le 1$ and allows to assess the level of interrelation between the random variables X_t and Y_t.

The significance test for the Pearson linear correlation coefficient of the analysed variables was carried out on the basis of the *t*-student test. It allowed to assess whether the existing relation between the variables from two dimensional normal arrangement X_t and Y_t is just random or is a regularity in a population. The analysed arrangement of hypotheses is : H0: $\rho = 0$, H1: $\rho \neq 0$.

For the data set, the problem is determined by the value of the *t*-student test, which, provided that the null hypothesis is true, has an arrangement $t_{(n-2)}$:

$$t_{(n-2)} = \frac{r_{xy}\sqrt{n-2}}{\sqrt{1-r_{xy}}} \tag{9}$$

where: r_{xy} - sample correlation coefficient, determined by the Eq. (6); $n - 2$ - degree of freedom for the independent samples; n - the number of monthly observations.

The critical set has the following form: $C = (-\infty, -t_{1-\alpha/2,n-2}) \cup (t_{1-\alpha/2,n-2}, \infty)$. If $|t| > t_{1-\alpha/2,\ n-2}$, the null hypothesis must be rejected.

The statistical analysis of research on the size of the demand for post-warranty repairs of agricultural tractors was carried out using the *R* program for Windows [29].

2 RESULTS

The subject selected for the purposes of the research was the service subsystem carried out in the authorised service station servicing vehicles and agricultural machines. This service station provides services for clients in Central-Eastern Poland. It is a technical service department in a company which is an official distributor of products of a dozen or so domestic and foreign producers of tractors and agricultural machines. The system of technical service is carried out by the service station activities in accordance with the standards of the quality assurance system in the field of environment management

The research was carried out in the service department and encompassed the total number of 6127 services of restoring the fitness for use of tractors in the post-warranty period, executed in the years 2003-2014. In such case the users have full freedom of selecting the location of commissioning technical service. However, various logistical and marketing programmes used by the dealers efficiently build groups of loyal customers among the purchasers of tractors and agricultural machines. Over the span of 12 years, i.e. in the period analysed during the research, the distributor sold 1731 pieces of agricultural vehicles. They were brand new products under the producer's warranty. The leading brand in the demand ranking was John Deere concern, whose tractors amounted to 84% of the sold vehicles. The remaining group consisted of Zetor, Same Deutz Fahr Group and Pronar tractors. The array of the number of repairs under the post-warranty period in a monthly arrangement executed by the service station in the years 2003-2014 had a variable quantitative structure, as presented in Fig. 2.

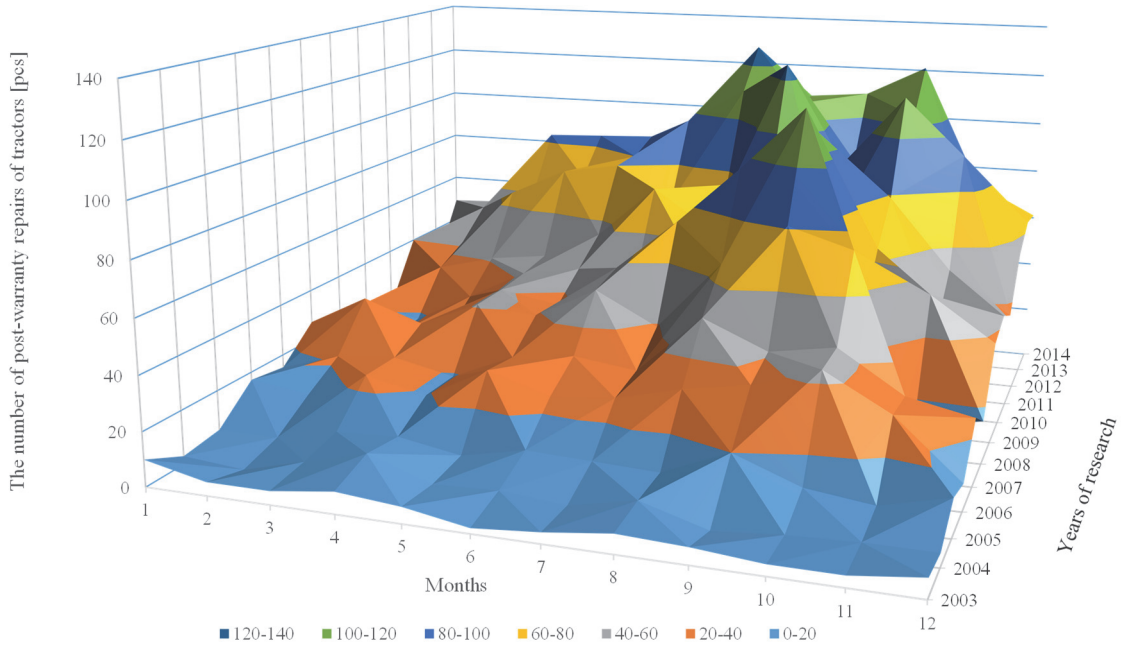

Figure 2 The arrangement of services carried out in the years 2003-2014 regarding post-warranty repairs of agricultural tractors

The structure of post-warranty repairs of tractors in a monthly arrangement in the years 2003-2014 is presented in Tab. 1. It should be noted that there was a regularity that emerged 9 times over a span of the analysed period, according to which the lowest demand for services occurred in January and February. In 2004, 2005, 2007 and 2009-2014 it reached the values from 1,56% to 4,74%. The minimum demand for repairs was also recorded in June 2003 (2,94%), December 2006 (3,25%) and November 2008 (2,33%). The significant increase in demand for technical service occurred in the period of execution of field agro technical procedures. The highest demand for services restoring operating usability of tractors in the years 2005-2014 varied from 12,12% to 20,31%. For the four-year period the maximum value was recorded in September, for the three-year period in August and once in October and July. One exception that occurred was a high demand in January 2003 (14,71%) and April 2004 (20,31%).

The ratio of the number of post-warranty repairs to the number of tractors in use sold by a distribution company in the years 2003-2014 is presented in Tab. 2. Comparing the level of demand for services to the population of agricultural tractors supplied to the local market confirms the choice of an authorized technical service by the users. The abovementioned activities guarantee maintaining quality standards in carrying out works that restore the operating usability. This is a criterion that illustrates the level of tractors' malfunctioning and unfitness for use and confirms that customers are loyal to the distribution and Service Company. In the analysed period there is a regularity in occurrence of the lowest level of service requests in relation to the analysed population of vehicles in the first months of the year.

Data obtained in the research in 2003 was excluded from analysis, because they did not include the number of vehicles sold in previous years. The analysis proved that the minimum percentage level of service works in relation

to the number of vehicles in the years: 2004, 2005, 2007, 2009-2014 reached the values from 0,68% to 3,13%. For the five-year period the minimum value occurred in January and for the four-year period in February. The research shows that the lowest demand for agricultural tractor maintenance services occurred in the post-warranty period in December 2006 (1,89%) and in November 2008 (1,64%). The highest commission level in the years 2004-2014 reached the values from 4,94% to 14,32%. The maximum was recorded over a span of eight years in two months: August and September, and only once in July. The only exception was the demand in April 2004 (4,94%).

Table 1 The structure of services carried out in the years 2003-2014 in the percentage arrangement in the field of post-warranty repairs of agricultural tractors

No.	Realisation time	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	In total
		%	%	%	%	%	%	%	%	%	%	%	%	pcs
1	2003	14,71	7,35	7,35	11,76	8,82	2,94	5,88	10,29	8,82	5,88	5,88	10,29	68
2	2004	4,69	1,56	10,94	20,31	7,81	9,38	6,25	14,06	3,13	6,25	7,81	7,81	64
3	2005	4,03	4,03	8,06	8,87	5,65	9,68	8,87	8,06	16,13	8,87	6,45	11,29	124
4	2006	5,52	4,55	7,79	6,17	10,06	7,79	8,44	10,39	11,69	14,29	10,06	3,25	308
5	2007	4,14	6,08	6,63	5,25	8,01	8,84	8,01	14,09	11,33	12,43	8,29	6,91	362
6	2008	5,24	7,57	6,02	7,96	7,57	9,9	7,57	12,62	15,73	14,37	2,33	3,11	515
7	2009	3,72	2,75	3,23	6,62	5,98	8,72	11,95	15,51	19,39	7,27	8,72	6,14	619
8	2010	4,12	3,23	5,38	7,53	8,24	7,89	9,5	9,14	19,18	11,47	6,81	7,53	558
9	2011	2,5	5,47	6,41	6,88	8,59	11,88	9,53	12,97	9,69	12,34	8,13	5,63	640
10	2012	4,35	4,46	7,07	8,27	8,71	7,18	8,16	13,71	9,47	12,51	10,12	5,98	919
11	2013	2,51	5,68	6,44	7,53	8,73	10,59	12,12	11,68	9,17	11,35	7,31	6,88	916
12	2014	4,74	4,84	8,03	8,12	8,22	8,22	12,28	10,35	10,54	11,7	7,06	5,9	1034

Table 2 The ratio of the number of maintenance services carried out in the years 2003-2014 to the number of tractors sold in the analogous period

No.	Realisation time	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
		%	%	%	%	%	%	%	%	%	%	%	%
1	2004	2,26	0,68	3,93	4,94	1,89	2,21	1,42	3,15	0,69	1,36	1,68	1,67
2	2005	1,67	1,6	3,11	3,3	2,06	3,48	3,11	2,76	5,39	2,92	2,02	3,47
3	2006	4,17	3,37	5,61	4,31	6,86	5,23	5,43	6,56	7,2	8,64	6,04	1,89
4	2007	2,8	4,03	4,31	3,35	5,03	5,46	4,91	8,54	6,77	7,25	4,77	3,94
5	2008	4,25	6,07	4,78	6,19	5,77	7,4	5,52	9,12	11,25	10,19	1,64	2,16
6	2009	3,06	2,24	2,6	5,22	4,64	6,66	9	11,58	14,32	5,28	6,25	4,37
7	2010	2,62	2,02	3,31	4,55	4,91	4,66	5,53	5,21	10,83	6,38	3,78	4,15
8	2011	1,57	3,42	3,92	4,12	5,06	6,91	5,43	7,23	5,27	6,57	4,22	2,86
9	2012	3,13	3,15	4,89	5,56	5,73	4,66	5,24	8,69	5,94	7,78	6,24	3,65
10	2013	1,52	3,42	3,83	4,44	5,11	6,15	6,98	6,71	5,24	6,44	4,13	3,86
11	2014	2,98	3,03	4,98	5,01	5,04	5,01	7,44	6,25	6,35	7,02	4,23	3,52

3 DISCUSSION

The analysis of the service commissions allowed to determine the trend of the number of repair services is presented in Fig. 3. The equal demand was recorded in the years 2003-2004, in 2005-2007 there was an increasing trend with big dynamics and in 2008 there was a reverse in the trend to a decreasing one.

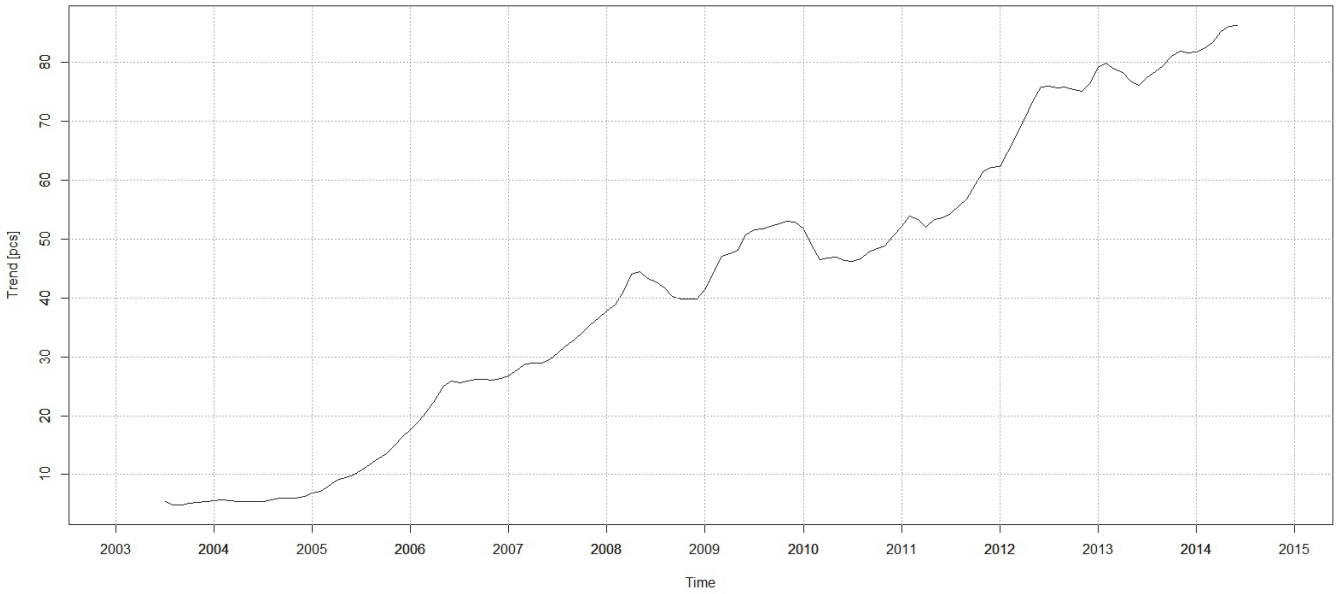

Figure 3 The trend of the number of services carried out in the years 2003-2014 during agricultural tractor repairs

Throughout 2009 the trend had a changeable dynamics, but it was steadily increasing. In 2010, after an initial decrease and subsequent demand stagnation, the increasing trend occurred which, with a slight correction,

maintained such tendency throughout the entire 2011 and the first half of 2012. The second half of 2012 and the first half 2013 resulted in the subsequent stagnation, increasing and then decreasing trend. In the second half of 2013 and the first half of 2014 there was an increasing trend of the provided services.

Random fluctuations of the number of repairs is presented in Fig. 4.

Their graphic analysis was made by comparing them to an average level which amounts to 100% for seasonal indexes. The value and course of random fluctuations for services were characterized by large heterogeneity and instability over a span of analysed years. The number of commissions carried out in subsequent months was significantly different and included both rises and falls in the demand level. The differences that had the highest demand value for servicing occurred in 2004, 2006, 2008 and 2009.

By eliminating the trend as well as the cyclic and random fluctuations, it was possible to determine the seasonal indexes value for the services (Fig. 5). The execution of transportation and agro technical procedures in agriculture and seasonal works in the forestry and municipal engineering had a significant impact on a time arrangement of the agricultural tractors usage. The number of services carried out in January and February, when no field works are conducted, was lower than the reference level by accordingly 41,7% and 38,5%. The maximum use of tractors during the summer and autumn field works indicated the increase in seasonal indexes from August to October by accordingly 44,5%, 43,5% and 23,4% above the average level. The end of the calendar year marked other drops of 15,7% and 26,4% below the reference level.

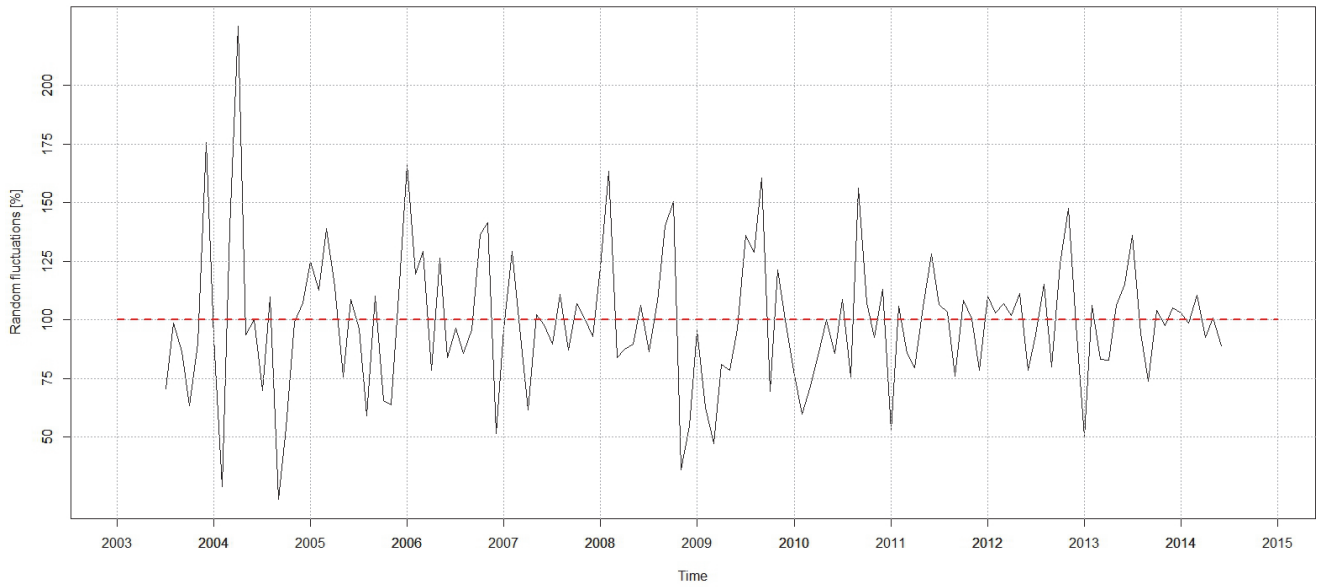

Figure 4 Random fluctuations of the number of services carried out in the years 2003-2014 during agricultural tractor repairs

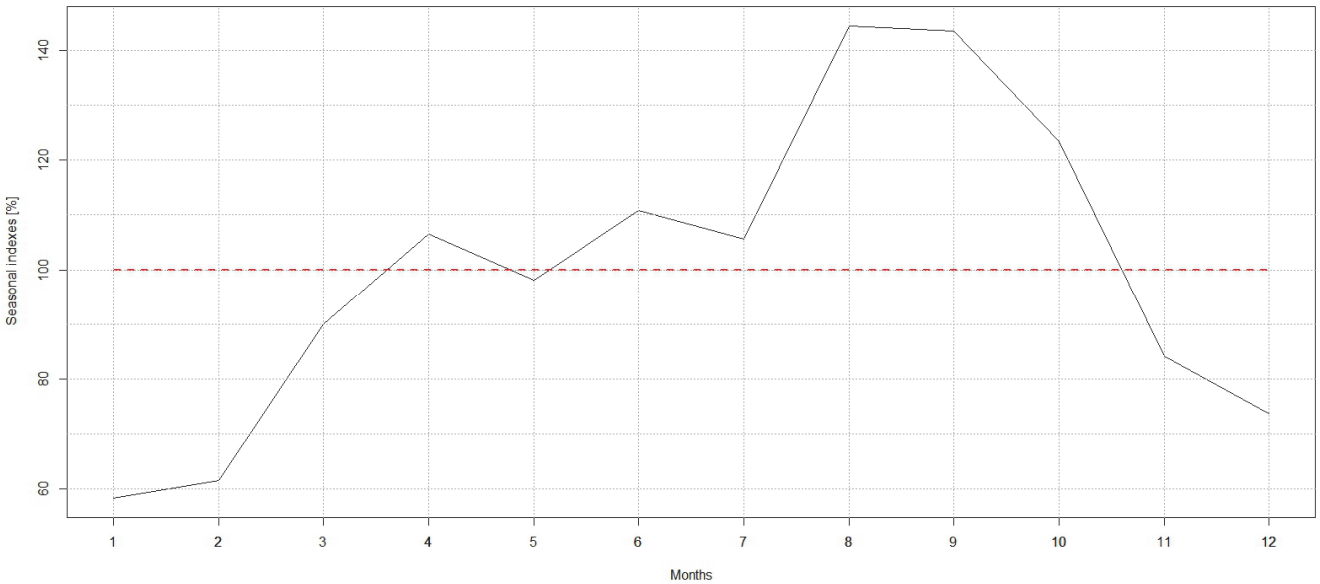

Figure 5 Seasonal indexes for the number of services carried out in the years 2003-2014 during agricultural tractor repairs

The correlation diagram between the number of services encompassing the post-warranty repairs and the number of agricultural tractors sold by the dealer to users in the years 2003-2014 is presented in Fig. 6. The correlation coefficient from the r_{xy} = 0,8181011 sample for the Y_t set of the number of services and the X_t set of

agricultural tractors that are used by the company's clients is a proof of the existence of a significant positive correlation between the analysed variables.

For the following conditions: $\alpha = 5\%$ trust level for the correlation coefficient, $n = 142$ number of degrees of freedom, $t_{0,975;\,142} = 1{,}97705$ critical value, the value of $t = 16{,}9522$ test statistics was calculated.

The $|t| > t_{1-\alpha/2,\,n-2}$ condition is met, which indicates that the correlation is statistically significant.

The null hypothesis on the independency of variables should be rejected in favour of the alternative hypothesis informing that the number of services in the post-warranty period and the number of agricultural tractors which are in use by the dealer's clients are interdependent in a linear way.

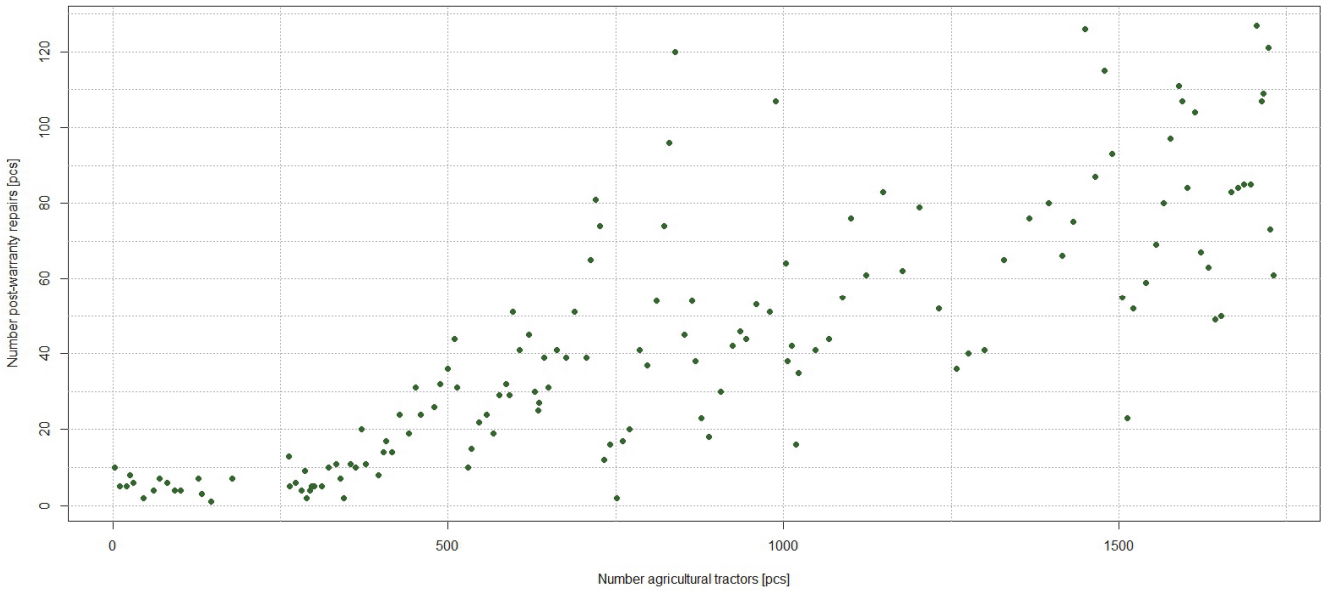

Figure 6 The correlation diagram between the number of services and the number of agricultural tractors sold by the dealer in the years 2003-2014

4 CONCLUSION

The modern systems of operation of tractors and agricultural machines encompassing the technical service over a lifespan of the product aim at fulfilling the needs and expectations of costumers. It has to be emphasized that all the key producers of tractors and agricultural machines on domestic market have already implemented system solutions in the technical service process. The subsystems of usage and operation have received a full support by means of the logistical system, which significantly reduces time required for carrying out inspections and refurbishing processes. In order to provide high quality services on time, it is necessary for the tractors' users to commission the service works to the authorised service stations.

The demand level for technical service in authorised service stations has varied. The amplitude of changes in needs for services in monthly periods fluctuated from a few of dozens to a couple of hundred percent. The distribution of tractors caused the increase in the local market saturation, which generated the increasing demand level for their servicing. The data analysis shows that the trend line determined for post-warranty services has varied over a span of the analysed period. Periods with an increasing trend with varied dynamics were dominant and, therefore, there was a general increase in the demand for technical services.

The analysed services had a large amplitude of random fluctuations. The stepwise change in demand reflected the intensity of the process of tractor operation. The risk of failure increased significantly in relation to the seasonal usage of agricultural tractors.

The acquired seasonal indexes values prove the cyclical changes of demand for servicing in subsequent months. The significant limitations resulting from environmental and climate conditions in carrying out agro technical procedures and transport works have resulted in significant drop in demand for services in the authorised service station. The analysis of the correlation between the number of warranty repairs and the number of tractors sold by a distribution company proved a positive linear interrelation. This confirms the tendency of the users who own modern agricultural tractors, to more and more common use of authorised services when it comes to carrying out technical services of the operated equipment.

The level of a service realized by the Service Department decides on a client's satisfaction and at the same time determines if the client will make use of the service package on offer. A satisfactory realization of the above-mentioned tasks in a longer run leads to the creation of the client's loyalty to the company. It must be mentioned that the products' servicing is of great concern due to multiplicity of the client's contacts with the provider during the whole product's exploitation period. Further research should be carried out on how agriculture is restructured in individual countries from Central and Eastern Europe and on modernization of farm technical equipment.

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