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Organizational and technological compatibility of the technological processes of three different types of third line maintenance of KhTZ-3522 tractors in the joint technological flow

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Summary. The work is dedicated to systematic substantiation of capacity, production structure and specialization of service station (SS) of KhTZ-3522 tractors. Based on the technical and economic comparative analysis of the results of modeling of the technological processes (TPs) of the third line maintenance, the third line maintenance before current repair (BCR) and the third line maintenance before major repair (BMR) of KhTZ-3522 tractors, the parametrical series of production structures of service stations (SSs) both mono- and poly technological specialization, which can work effectively in a wide range of the general annual program of orders, and in the conditions of seasonal fluctuations of orders for the maintenance of these tractors, are founded. The results of calculations of the system of indicators of organizational and technological compatibility (OTC) of the TPs of the third line maintenance, the third line maintenance BCR and the third line maintenance BMR of KhTZ-3522 tractors in the joint technological flow are presented. The dependencies of these indicators on the total annual program of orders for SSs of different productivity are analyzed. According to the results of the analysis, the poly technological specialization of such service stations is substantiated.

Key words: KhTZ-3522 tractors, maintenance, technological processes, organizational and technological compatibility, service stations, specialization.

INTRODUCTION

New tractors KhTZ-3510 (drawbar category – 0,9) and KhTZ-3522 (drawbar category – 1,4), manufactured by Kharkiv Tractor Plant (KhTZ), appeared in small agrarian enterprises of Ukraine in the early 2000's. However, the technical service base for these new KhTZ tractor brands has not yet been created in Ukraine.

The achievement of high values of the coefficient of technical use of these tractors presumes timely and qualitative maintenance. The manufacturer provided five different types of maintenance for these tractors: first (service interval – 250 hours), second (service interval – 500 hours) and third (service interval – 1000 hours) line maintenance and additionally third line maintenance before current repair (service interval – 2000 hours) and third line maintenance before main repair (service interval – 8000 hours). The list of operations for each type of maintenance is determined by the manufacturer [1, 2]. The structure of technical maintenance cycle is organized so that operations of all previous line maintenances are included in the following line maintenance.

Research of TPs of maintenance was carried out on an example of tractors KhTZ-3522, since these tractors are constructively more complex then KhTZ-3510 tractors – they are equipped with front drive axle.

To perform the operations of third line maintenance of KhTZ-3522 tractors need to use 15 different types of special equipment and tools (r = 15), to perform the operations of third line maintenance before current repair (BCR) – 21 different types (r = 21) and to perform the operations of third line maintenance before main repair (BMR) – 26 different types (r = 26). Therefore, qualified masters at stationary posts of service stations must carry out these complex types of maintenance [3, 4].

Creating an effective repair and servicing base for agriculture techniques requires scientific systematic approach, based on the application of methods of structural and parametric optimization of technical service processes, in particular, technological processes that are performed on stationary posts [5].

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The substantiation of the program W_A, the performance Q_A, the production structure and the specialization of the technical service enterprises is a complex system task [5], which involves the use of an iterative procedure for the solution of interdependent parametric and structural optimization tasks [6].

Regarding the technical service processes performed on stationary posts, the task of substantiating their parameters and structure was for the first time solved using the graph theory and schedules for the TP of the current repair of tractors [7], but the interdependence between all parameters and performance indicators of the TP was not taken into account.

The application of the iteration procedure has made it possible to eliminate this defect in relation to the tasks of determining the parameters and indicators of efficiency of the TPs of maintenance of KhTZ tractors [8-12], as well as the substantiation of the production structure of the SSs of KhTZ tractors [13, 14].

The ground for the determination of specialization of selected production units of the technical service enterprises is OTC of the processes performed there [15, 16]. The property of the OTC is determined by the similarity of the construction design of the machines and the technology of work, the flexibility of the equipment used, the similarity of the structure of different TPs, which are united in the joint technological flow, and also depends on the overall annual program of work (general program), and on the quantitative proportion of various processes (partial programs) in the general program. If for a certain value of a general program and a certain proportion of partial programs, the cost of implementing different TPs in the joint flow is less than the cost of implementing the same TPs separately, then it is considered to be OTC of these processes [17].

The system of indicators for the assessment of the OTC both for a separate value of productivity of production lines or stations and to evaluate OTC for production lines or stations in general has been previously well-grounded [15–19]. The dependences of OTC indices on the work level of production lines and production units is also researched [20].

In the case of OTC of the different TPs, a multidisciplinary or poly technological specialization is appropriate.

OBJECTIVES

The work purpose is to increase the efficiency of the third line technical service of the KhTZ-3522 tractors by way of substantiation of the specialization (mono- or poly technological) of branded SSs of different capacity and production structure from the corresponding parametric series.

THE MAIN RESULTS OF THE RESEARCH

The sets of possible different variants of production structures of service stations, which provide the same annual Q_A capacity, has been synthesized according to the results of the analysis of the mutual dependencies between different parameters and performance indicators of TPs of all three different types of third line maintenance of KhTZ-3522 tractors. Those mutual dependencies are obtained by modeling these TPs using the theory of graphs and heuristic algorithms of the theory of schedules [9].

The feasibility and economic comparison of various possible options was made on the basis of the total cash expenditure for the entire annual maintenance program ΣZ. The total cash ΣZ included the costs determined by the production structure of the service station Z_{SS} (wages of workers, allowance for keeping and depreciation of equipment and industrial premises, payment for power electric etc.), and also the costs which are determined by the technology of performance Z_{lm} (costs for fuel, lubricants and other process materials etc.). The arrangement of the comparison results made it possible to form parametric series of SSs for KhTZ-3522 tractors (Tables 1–3) with different production structure and capacity of mono technological specialization (for the performance of only third line technical maintenance or only third line technical maintenance BCR or only third line technical maintenance BMR respectively). The optimal capacity for each maintenance item from the parametric series was determined by the criterion for minimizing specific costs ($C = \Sigma Z/Q_A) \rightarrow$ min.

Initially, the parametric series of production structures of SSs for all three options of mono technological specialization (for third line maintenance only, for third line maintenance BCR only and for third line maintenance BMR only) was based on results of simulation of the corresponding three different TPs of maintenance of KhTZ-3522 tractors (Tables 1–3).

Five different variants of production structures have been included to each parametric series of SSs for all three options of mono technological specialization. These variants differ in the number of equipment of individual types (high-pressure jet cleaners Karcher K5 Compact K_{r1}, mobile machines Flexbimec-5903 for washing parts K_{r6} and universal devices C-230 for oiling K_{r7}), in the number of stationary posts f, and, consequently, in the production area. The list of all other types of required equipment for each of the three options of KhTZ-3522 tractors maintenance is determined by the technology of work [16, 20]. Since all other types of necessary equipment are intended to perform only one operation, the number of equipment of all other types K_r = 1 pcs.

The capacity of each variant of the production structure of the SS may vary within a sufficiently wide range, depending on the number of employees engaged, which enables the adaptation of SS performance to seasonal variations in the number of orders as well as the annual change in the number of tractors in the service area

For example (Table 1), the variant I of the production structure of the SS for the third line maintenance of KhTZ-3522 tractors can provide maximum annual capacity Q_A = 625 orders per year, if the number of workers is u = 4 persons. If the number of workers is u = 1 person, then annual capacity will be only Q_A = 229 orders per year. For this production structure of SS the optimal performance that meets the minimum specific costs is 589 orders per year, when three workers work (u = 3 persons).

The variant II of the production structure of the SS for the third line maintenance only is characterized by an increase in the number of equipment (high-pressure jet washing machines Karcher K5 Compact K_{r1}= 4 pcs, mobile machines Flexbimec-5903 for washing parts K_{r6} = 2 pcs and universal devices C-230 for filling oil K_{r7} = 2 pcs). This variant can provide maximum annual capacity Q_A = 694 orders per year, if the number of workers is u = 8 persons. For this production structure optimal performance is a bit bigger and it is 638 orders per year, when three workers work (u = 3 persons).

The next three variants of the production structure of the SSs for the third line maintenance only (mono technological specialization) of KhTZ-3522 tractors are characterized by an increase in the number of posts f and in some cases by an increase working area respectively (since according to building regulations the production area can be increased in increments of 36 m^2).

Each next variant has a wider range of productivity changes by attracting a different number of workers. The optimal performance of each next variant is also higher than the previous one and it is achieved for an ever greater number of workers.

To the parametric series of SSs for the third line maintenance BCR only (Table 2) and for the third line maintenance BMR only (Table 3) of KhTZ-3522 tractors also includes five different variants of production structures. These variants are very similar to the corresponding variants of production structures of SSs for the third line maintenance of these tractors only and differ merely in the use of additional types of main equipment (r = 21 and r = 26 respectively).

Table 1. The parametric series of service stations (SS) with different production structure and capacity for the third line maintenance of KhTZ-3522 tractors

№ of SS	Annual capacity Q_A, orders	Amount of equipment and tools*, pcs.			Number of posts f, units	Number of workers u, persons	Economic indicators, UAH			
		K_{r1}	K_{r6}	K_{r7}			Z_{SS}	Z_{l-m}	ΣZ	C
I	229	1	1	1	1	1	122966,21	1822649,93	1945616,3	8496,14
	440					2	170966,21	3502034,8	3673001,0	8347,73
	589 ^{opt}					3 ^{opt}	218966,21	4687951,13	4906917,3	8330,93
	625					4	266966,21	4974481,25	5241447,5	8386,32
II	229	4	2	2	1	1	131659,21	1822649,93	1954309,1	8534,1
	458					2	179659,21	3645299,86	3824959,1	8351,44
	638 ^{opt}					3 ^{opt}	227659,21	5077950,46	5305609,7	8316,0
	694					4	275659,21	5523663,98	5799323,2	8356,37
III	229	4	2	2	2	1	144007,72	1822649,93	1966657,7	8588,02
	464					2	192007,72	3693054,88	3885062,6	8372,98
	696					3	240007,72	5539582,32	5779590,0	8304,01
	936					4	288007,72	7449783,12	7737790,8	8266,87
	1118 ^{opt}					5 ^{opt}	336007,72	8898352,06	9234359,8	8259,71
	1254					6	384007,72	9980799,18	10364806,9	8265,4
	1335					7	432007,72	10625492,0	11057499,7	8282,77
	1408					8	480007,72	11206511,4	11686519,1	8300,08
IV	229	4	2	2	3	1	159466,64	1822649,93	1982116,6	8655,53
	471					2	207466,64	3748769,07	3956235,7	8399,65
	704					3	255466,64	5603255,68	5858722,3	8322,05
	932					4	303466,64	7417946,44	7721413,1	8284,78
	1156					5	351466,64	9200800,52	9552267,2	8263,21
	1344					6	399466,64	10697124,5	11096591,1	8256,39
	1533 ^{opt}					7 ^{opt}	447466,64	12201407,6	12648874,3	8251,06
	1656					8	495466,64	13180385,5	13675852,2	8258,36
	1725					9	543466,64	13729568,3	14273034,9	8274,22
	1815					10	591466,64	14445893,6	15037360,2	8285,05
V	229	4	2	2	4	1	182032,94	1822649,93	2004682,9	8754,07
	472					2	230032,94	3756728,24	3986761,2	8446,53
	706					3	278032,94	5619174,02	5897207,0	8352,98
	936					4	326032,94	7449783,12	7775816,1	8307,5
	1169					5	374032,94	9304269,73	9678302,7	8279,13
	1389					6	422032,94	11055287,1	11477320,1	8263,01
	1580					7	470032,94	12575488,6	13045521,5	8256,66
	2379					8	518032,94	13840996,6	14359029,6	8257,06
	1934 ^{opt}					9 ^{opt}	566032,94	15393034,8	15959067,7	8251,84
	2070					10	614032,94	16475481,9	17089514,8	8255,8
	2178					11	662032,94	17335072,3	17997105,2	8263,13
	2250					12	710032,94	17908132,5	18618165,4	8274,74
	2325					13	758032,94	18505070,3	19263103,2	8285,21
	2379					14	806032,94	18934865,4	19740898,4	8297,98

* Amount of equipment and tools: $K_{r2} = K_{r3} = K_{r4} = K_{r5} = K_{r8} = K_{r9} =…= K_{r15}$ = 1 pcs.

Table 2. The parametric series of service stations (SSs) with different production structure and capacity for the third line maintenance before current repair (BCR) of KhTZ-3522 tractors

№ of SS	Annual capacity Q_A, orders	Amount of equipment and tools*, pcs.			Number of posts f, units	Number of workers u, persons	Economic indicators, UAH			
		K_{r1}	K_{r6}	K_{r7}			Z_{SS}	$Z_{l\text{-}m}$	ΣZ	C
I	133	1	1	1	1	1	174853,22	1145058,18	1319911,4	9924,15
	260					2	222853,22	2238459,6	2461312,8	9466,59
	377					3	270853,22	3245766,42	3516619,6	9327,9
	462 opt					4 opt	318853,22	3977570,52	4296423,7	9299,62
	491					5	366853,22	4227244,86	4594098,1	9356,62
	501					6	414853,22	4313339,46	4728192,7	9437,51
II	133	4	2	2	1	1	183546,22	1145058,18	1210165,6	11001,51
	267					2	231546,22	2298725,82	2208399,5	10038,18
	398					3	279546,22	3426565,08	3189356,4	9723,65
	506					4	327546,22	4356386,76	3772942,8	9674,21
	536 opt					5 opt	375546,22	4614670,56	4641599,4	9570,31
	546					6	423546,22	4700765,16	4732791,8	9658,76
III	133	4	2	2	2	1	199005,14	1145058,18	1344063,3	10105,74
	268					2	247005,14	2307335,28	2554340,4	9531,12
	401					3	295005,14	3452393,46	3747398,6	9345,13
	540					4	343005,14	4649108,40	4992113,5	9244,65
	672					5	391005,14	5785557,12	6176562,3	9191,31
	796 opt					6 opt	439005,14	6853130,16	7292135,3	9160,97
	877					7	487005,14	7550496,42	8037501,6	9164,77
	945					8	535005,14	8135939,70	8670944,8	9175,6
	953					9	583005,14	8204815,38	8787820,5	9221,22
IV	133	4	2	2	3	1	199005,14	1145058,18	1477961,0	10105,74
	271					2	247005,14	2333163,66	2580168,8	9520,92
	406					3	295005,14	3495440,76	3790445,9	9336,07
	539					4	343005,14	4640498,94	4983504,1	9245,83
	667					5	391005,14	5742509,82	6133515,0	9195,67
	793					6	439005,14	6827301,78	7266306,9	9163,06
	892 opt					7 opt	487005,14	7679638,32	8166643,5	9155,43
	936					8	535005,14	8058454,56	8593459,7	9181,05
	940					9	583005,14	8092892,40	8675897,5	9229,68
	953					10	631005,14	8204815,38	8835820,5	9271,59
	967					11	679005,14	8325347,82	9004353,0	9311,64
	981					12	727005,14	8445880,26	9172885,4	9350,55
V	133	4	2	2	4	1	221571,44	1145058,18	1366629,6	10275,41
	271					2	269571,44	2333163,66	2602735,1	9604,19
	406					3	317571,44	3495440,76	3813012,2	9391,66
	540					4	365571,44	4649108,4	5014679,8	9286,44
	672					5	413571,44	5785557,12	6199128,6	9224,89
	799					6	461571,44	6878958,54	7340530,0	9187,15
	888					7	509571,44	7645200,48	8154771,9	9183,30
	936 opt					8 opt	557571,44	8058454,56	8616026	9205,16
	953					9	605571,44	8204815,38	8810386,8	9244,90
	967					10	653571,44	8325347,82	8978919,3	9285,34
	981					11	701571,44	8445880,26	9147451,7	9324,62
	995					12	749571,44	8566412,7	9315984,1	9362,80
	1024					13	797571,44	8816087,04	9613658,5	9388,34
	1061					14	845571,44	9134637,06	9980208,5	9406,42

* Amount of equipment and tools: $K_{r2} = K_{r3} = K_{r4} = K_{r5} = K_{r8} = K_{r9} = \ldots = K_{r21} = 1$ pcs.

Table 3. The parametric series of service stations (SSs) with different production structure and capacity for the third line maintenance before main repair (BMR) of KhTZ-3522 tractors

№ of SS	Annual capacity Q_A, orders	Amount of equipment and tools*, pcs.			Number of posts f, units	Number of workers u, persons	Economic indicators, UAH			
		K_{r1}	K_{r6}	K_{r7}			Z_{SS}	$Z_{l\text{-}m}$	ΣZ	C
I	110	1	1	1	1	1	251238,7	950233,9	1201472,6	10922,48
	216					2	299238,7	1865913,8	2165152,6	10023,85
	314					3	347238,7	2712485,9	3059724,6	9744,35
	361 opt					4 opt	395238,7	3118494,9	3513733,6	9733,33
	372					5	443238,7	3213518,3	3656757	9829,99
	375					6	491238,7	3239433,8	3730672,5	9948,46
II	110	4	2	2	1	1	259931,7	950233,9	1210165,6	11001,51
	220					2	307931,7	1900467,8	2208399,5	10038,18
	328					3	355931,7	2833424,7	3189356,4	9723,65
	390					4	403931,7	3369011,1	3772942,8	9674,21
	485 opt					5 op	451931,7	4189667,7	4641599,4	9570,31
	490					6	499931,7	4232860,1	4732791,8	9658,76
III	110	4	2	2	2	1	275390,6	950233,9	1225624,5	11142,04
	222					2	323390,6	1917744,8	2241135,4	10095,2
	332					3	371390,6	2867978,7	3239369,3	9757,14
	443					4	419390,6	3826851,1	4246241,7	9585,20
	543					5	467390,6	4690700,1	5158090,7	9499,25
	634					6	515390,6	5476802,7	5992193,3	9451,41
	699 opt					7 op	563390,6	6038304,5	6601695,1	9444,49
	744					8	611390,6	6427036,6	7038427,2	9460,25
	766					9	659390,6	6617083,3	7276474,0	9499,31
	778					10	707390,6	6720745,2	7428135,9	9547,73
IV	110	4	2	2	3	1	275390,6	950233,9	1225624,5	11142,04
	223					2	323390,6	1926383,3	2249773,9	10088,67
	334					3	371390,6	2885255,7	3256646,3	9750,44
	444					4	419390,6	3835489,6	4254880,2	9583,06
	554					5	467390,6	4785723,5	5253114,1	9482,16
	657					6	515390,6	5675487,9	6190878,8	9422,95
	747					7	563390,6	6452952,3	7016342,7	9392,69
	831 opt					8 opt	611390,6	7178585,2	7789975,8	9374,22
	884					9	659390,6	7636425,2	8295815,8	9384,41
	932					10	707390,6	8051072,7	8758463,3	9397,49
	945					11	755390,6	8163373,1	8918763,7	9437,85
	953					12	803390,6	8232481,0	9035871,6	9481,50
V	110	4	2	2	4	1	297956,9	950233,9	1248190,8	11347,19
	224					2	345956,9	1935021,8	2280978,7	10182,94
	335					3	393956,9	2893894,2	3287851,1	9814,48
	446					4	441956,9	3852766,5	4294723,5	9629,42
	559					5	489956,9	4828915,9	5318872,9	9514,98
	659					6	537956,9	5692764,9	6230721,9	9454,81
	761					7	585956,9	6573890,9	7159847,8	9408,47
	866 opt					8 opt	633956,9	7480932,3	8114889,3	9370,54
	900					9	681956,9	7774641	8456597,9	9396,22
	958					10	729956,9	8275673,4	9005630,4	9400,45
	976					11	777956,9	8431166,2	9209123,2	9435,58
	985					12	825956,9	8508912,7	9334869,6	9477,02
	1009					13	873956,9	8716236,4	9590193,4	9504,65
	1029					14	921956,9	8889006,2	9810963,2	9534,46

* Amount of equipment and tools: $K_{r2} = K_{r3} = K_{r4} = K_{r5} = K_{r8} = K_{r9} =\ldots= K_{r26} = 1$ pcs.

However, it should be noted that for similar variants of the production structure, the maximum and optimal values of annual capacity of SSs for the third line maintenance BMR of KhTZ-3522 tractors are significantly lower than the corresponding values of SSs for the third line maintenance.

For example, the maximum annual capacity of the variant III of the production structure of the SS for the third line maintenance of KhTZ-3522 tractors is Q_A = =1408 orders per year, the maximum annual capacity of the variant III of the production structure of the SS for the third line maintenance BCR of KhTZ-3522 tractors is Q_A= 953 orders per year and the maximum annual capacity of variant III of the production structure of the service station for the third line maintenance BMR of KhTZ-3522 tractors is only Q_A = 778 orders per year. This significant difference is explained by the greater labor-intensive characteristics of the TPs of the third line maintenance BCR and the third line maintenance BMR respectively.

Because all operations of the third line maintenance and the third line maintenance BCR of KhTZ-3522 tractors are also performed during the third line maintenance BMR of these tractors, therefore the parametric series of SSs of mono technological specialization for the third line maintenance BMR only corresponds to the parametric series of SSs of poly technological specialization of KhTZ-3522 tractors, where you can perform all three different types of third line maintenance in the joint technological flow (Table 4).

It should be noted, that the capacity of SSs for maintenance of KhTZ-3522 tractors of the poly technological specialization depends on the ratio of orders for different types of maintenance: maximum capacity $Q_{A\ \max}$ is reached, when all orders will be executed for only the third line maintenance, but minimal capacity $Q_{A\ \min}$, when all orders will be for the third line maintenance BMR only (Table 4). For example, the maximum annual capacity of variant III of the production structure of the SS of the poly technological specialization for all different types of third line maintenance of KhTZ-3522 tractors when eight workers work (u = 8 persons) is $Q_{A\ \max}$ = 1408 orders for the third line maintenance, and the minimum annual capacity $Q_{A\ \min}$ = 744 orders for the third line maintenance BMR.

For the quantitative assessment of the properties of the OTC, the system of indicators with a certain technical, technological and production content [7] is used, and the method for calculating these indices has been developed in advance [14].

The system of OTC indicators includes coefficients of OTC α_W, level of OTC β_W and relative level of OTC γ_W, that are calculated for a particular value of the annual program $W_{A\ \min}$, provided, that any ratio of partial programs of orders for all different types of technical maintenance in the total program of orders $W_{A\ \min}$ is equally probable.

When diverse combinations of different TPs in the joint technological flow are considered, then full compatibility of all types of maintenance, as well as many variants of partial compatibility, are possible. Partial compatibility of TPs occurs in the case when it is expedient to perform in a joint flow only two of three different TPs (for example, two TPs of the three line maintenance BCR and of the three line maintenance BMR in the joint technological flow and TP of the three line maintenance of KhTZ-3522 tractors – separately).

Dependencies of OTC indicators of the TPs of all three different types of third line maintenance of KhTZ-3522 tractors in the joint technological flow on annual program $W_{A\ \min}$ (by the number of orders for third line maintenance BMR), received for variant V of the production structure of the SS of the poly technological specialization (Table 4), shown in Figures 1–4. These are interrupted functions whose breakpoints correspond to those of the total annual program $W_{A\ \min}$ for which there is a change in the number of workers.

As you can see (Figures 1, a, b) on the intervals of continuity with growing the total annual program $W_{A\ \min}$ the values of the coefficient of complete OTC α_W and the coefficient of the level of complete OTC β_W remains constant, if a complete OTC of TPs of various types of maintenance in the joint technological flow is in evidence ($\alpha_W = \beta_W = 1$), or decreases or increases nonlinearly.

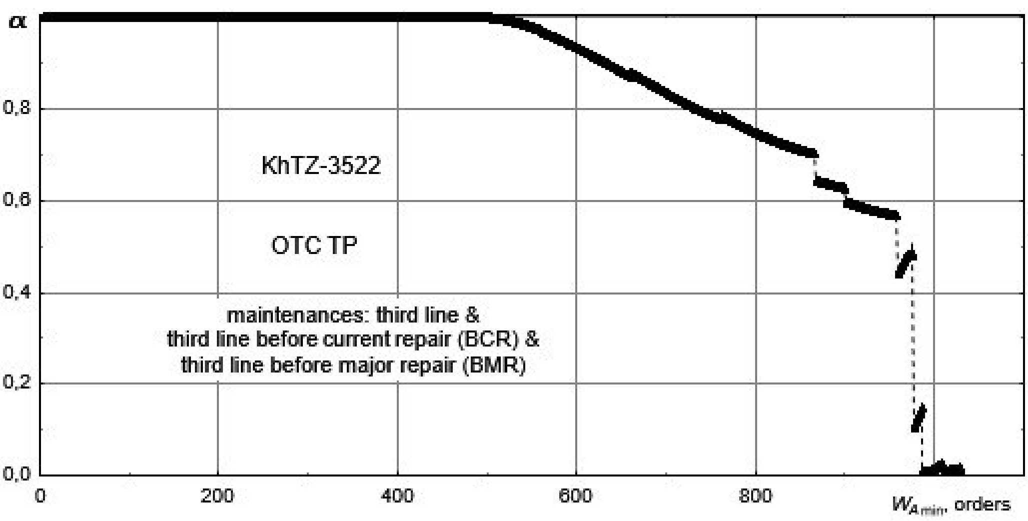
As you can see (Figures 1, c) when the program $W_{A\ \min}$ increases, the values of the coefficient of the relative level of complete OTC γ_W on the intervals of continuity remains constant or nonlinearly increases even if a complete OTC of TPs of all types of the third line maintenance of KhTZ-3522 tractors ($\alpha_W = \beta_W = 1$) in a joint flow is in evidence.

As you can see (Figure 2, b) for the partial OTC with growing the total annual program $W_{A\ \min}$ the values of the coefficient of partial OTC $\alpha_{3,CR}$, $\alpha_{3,MR}$, $\alpha_{CR,MR}$ the coefficient of the level of partial OTC $\beta_{3,CR}$, $\beta_{3,MR}$, $\beta_{CR,MR}$ and the coefficient of the relative level of partial OTC γ_{3,CR_3}, $\gamma_{3,MR}$, $\gamma_{CR,MR}$ remains constant and equal 0 on the intervals of continuity, if a complete OTC of TPs of all various types of the third line maintenance of KhTZ-3522 tractors in the joint technological flow is in evidence ($\alpha_W = \beta_W = 1$).

For the values of an annual program $W_{A\ \min}$, where $\alpha_W < 1$ and $\beta_W < 1$, indicators of partial OTC $\alpha_{3,CR}$, $\alpha_{3,MR}$, $\alpha_{CR,MR}$, $\beta_{3,CR}$, $\beta_{3,MR}$, $\beta_{CR,MR}$ and γ_{3,CR_3}, $\gamma_{3,MR}$, $\gamma_{CR,MR}$ decrease or increase nonlinearly on the intervals of continuity.

At the same time, for all values of the annual program $W_{A\ \min}$, for which the organizational and technological incompatibility is not detected, such constraining conditions are valid (Figures 2 – 4):

a) sum of values of the coefficients of complete OTC and of partial OTC of TPs of all different maintenances of KhTZ-3522 tractors in the joint technological flow is equal to 1:
$$\alpha_W + \alpha_{3,CR} + \alpha_{3,MR} + \alpha_{CR,MR} = 1; \qquad (1)$$
b) sum of values of the coefficients of level of complete OTC and partial OTC of TPs of all different maintenances of KhTZ-3522 tractors in the joint technological flow is also equal to 1:
$$\beta_W + \beta_{3,CR} + \beta_{3,MR} + \beta_{CR,MR} = 1. \qquad (2)$$
c) sum of values of the coefficients of relative level of complete OTC and partial OTC of TPs of all different maintenances of KhTZ-3522 tractors in the joint technological flow is greater than 0:
$$\gamma_W + \gamma_{3,CR} + \gamma_{3,MR} + \gamma_{CR,MR} > 0. \qquad (3)$$



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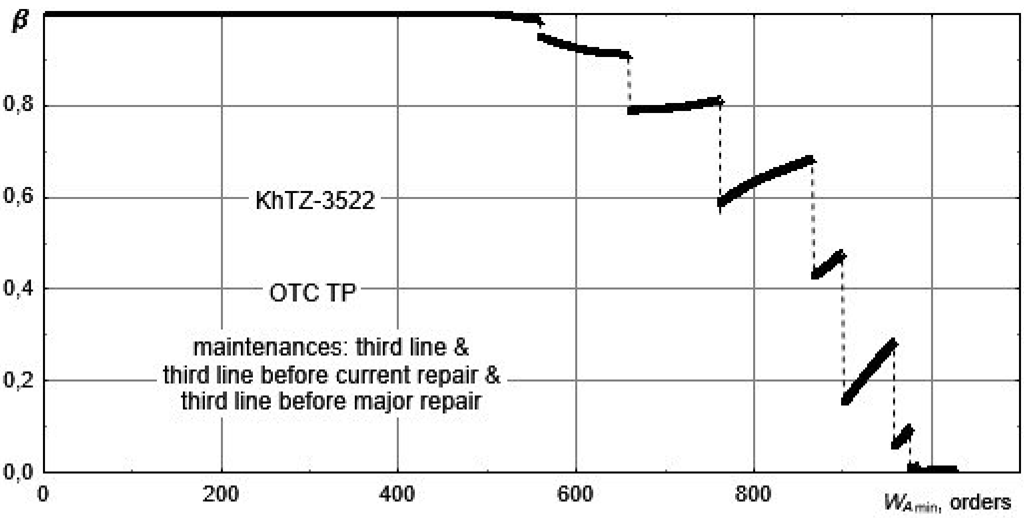

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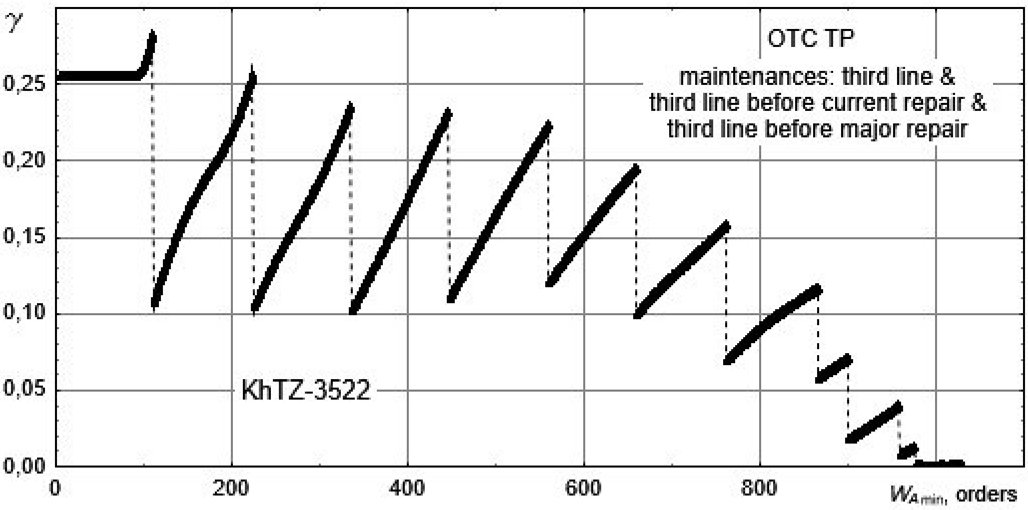


c)

Fig. 1. Dependences of the indices of complete OTC of TPs of all different maintenances of KhTZ-3522 tractors in the joint technological flow on the annual number of orders for maintenance before main repair (BMR) $W_{A\ \min}$ for variant V of the production structure of the SS of poly technological specialization

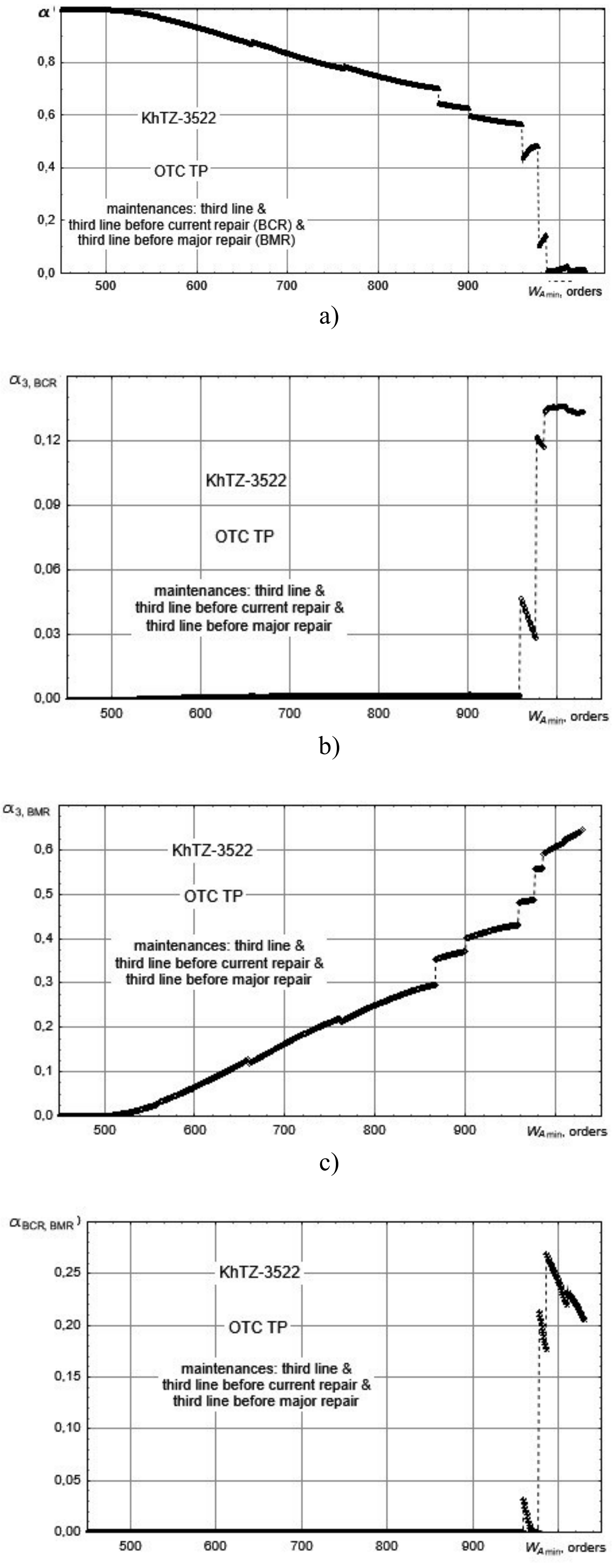


Fig. 2. Dependences of the coefficients of complete and partial OTC of TPs of all different types of third line maintenances of KhTZ-3522 tractors in the joint technological flow on the annual number of orders for the third line maintenance before main repair (BMR) $W_{A\ \min}$ for variant V of the production structure of the SS of poly technological specialization

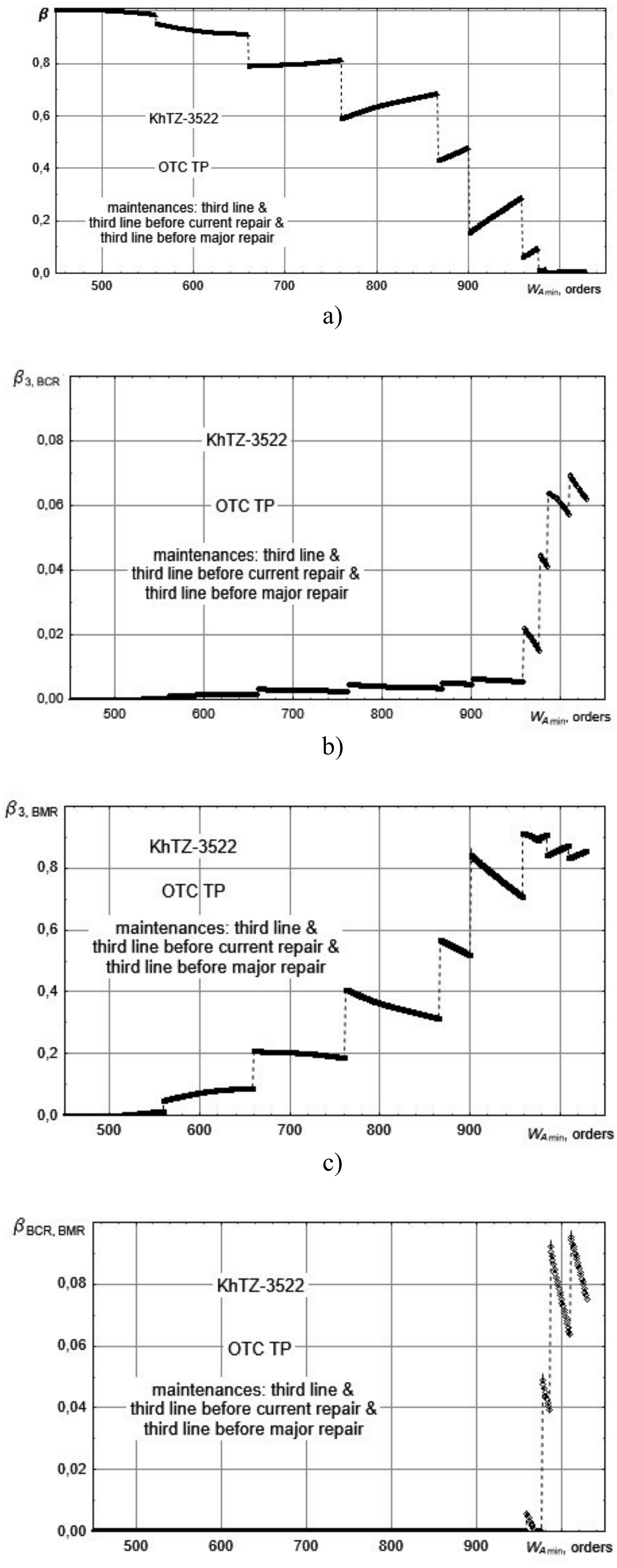
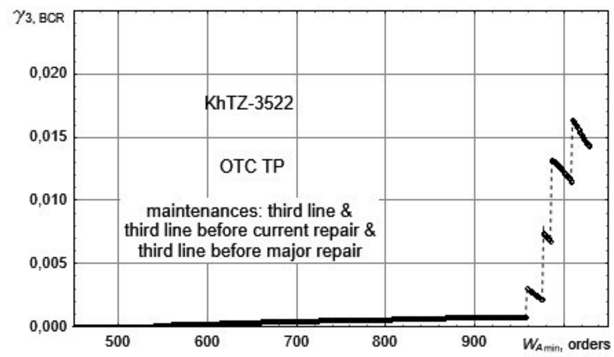
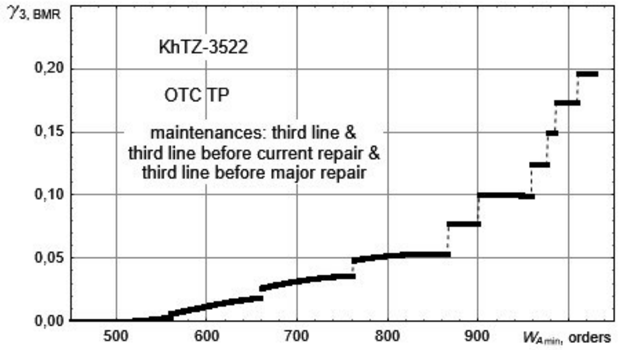


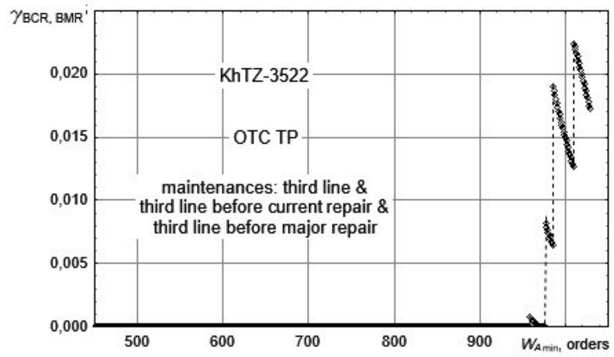
Fig. 3. Dependences of the coefficients of level of complete and partial OTC of TPs of all different types of third line maintenances of KhTZ-3522 tractors in the joint technological flow on the annual number of orders for the third line maintenance before main repair (BMR) $W_{A\ \min}$ for variant V of the production structure of the SS of poly technological specialization



a)



b)



c)

Fig. 4. Dependences of the coefficients of relative level of complete and partial OTC of TPs of all different types of third line maintenances of KhTZ-3522 tractors in the joint technological flow on the annual number of orders for the third line maintenance before main repair (BMR) $W_{A\ \min}$ for variant V of the production structure of the SS of poly technological specialization

The analysis of the results of calculating the values of complete OTC indicators of the TPs of all three different types of third line maintenance for SSs of poly technological specialization with different production structure and capacity from parametric series (Tables 4, 5), which was conducted under the additional condition that any values of the annual program $W_{A\ \min}$ (by the annual number of third line BMR maintenance orders), that are possible for a constant number of workers u = =const, are equally probable, allowed to reveal certain regularities.

Firstly, for each variant of the production structure of the SSs, with an increase in the number of workers u, the values of complete `OTC indexes does not increase. For example, for variant III of the production structure of the SS, where the TPs of all maintenance of tractors KhTZ-3522 are executed in the joint technological flow by two workers (u = 2 persons) – $\alpha = \beta = 1{,}0$ i $\gamma = 0{,}2809$; and when u = 8 persons – $\alpha = 0{,}8701$, $\beta = 0{,}7826$, $\gamma = 0{,}1109$ (Table 4).

Secondly, for SSs with a more complex production structure and higher capacity the values of the complete OTC indicators are lower. For example, if for the variant III of the production structure of the SS in general was received $\alpha = 0{,}9674$, $\beta = 0{,}8986$ i $\gamma = 0{,}1577$, then for fifth variant of the production structure of the SS in general – $\alpha = 0{,}8524$, $\beta = 0{,}5031$ i $\gamma = 0{,}0829$ (Table 4).

Thirdly, because for all five variants of production structure of SSs of poly technological specialization from parametric series (Table 4) in general the condition $\beta >$ >0.5 is fulfilled, so implementation of the TPs of all three different types of third line maintenances of KhTZ-3522 tractors in the joint technological flow is expedient [12, 14].

The analysis of the results of calculating of the values of partial OTC indicators for SSs of poly technological specialization with different production structure and capacity from parametric series (Table 5), which was conducted under the additional condition that any values of the annual program $W_{A\ \min}$ (by the annual number of third line BMR maintenance orders), that are possible for a constant number of workers u = const, are equally probable, allowed to reveal another certain regularities.

For each variant of the production structure of the SSs of poly technological specialization, with an increase in the number of workers u, the values of indexes of partial `OTC does not decrease. For example, for variant III of the production structure of the SS of poly technological specialization), when the TPs of maintenance of KhTZ-3522 tractors are executed by six workers (u = 6 persons) was received $\alpha_{3,CR} = 0{,}0008$, $\beta_{3,CR} = 0{,}0007$ and $\gamma_{3,CR} = 0{,}0001$; $\alpha_{3,MR} = 0{,}0291$, $\beta_{3,MR} =$ $=0{,}0246$ and $\gamma_{3,MR} = 0{,}0049$; $\alpha_{CR,MR} = 0$, $\beta_{CR,\ MR} = 0$ and $\gamma_{CR,MR} = 0$; and when the TPs of maintenance of tractors KhTZ-3522 are executed by nine workers (u = 9 persons) – $\alpha_{3,CR} = 0{,}0019$, $\beta_{3,CR} = 0{,}0069$ and $\gamma_{3,CR} = 0{,}0007$; $\alpha_{3,MR} = 0{,}1457$, $\beta_{3,MR} = 0{,}4106$ and $\gamma_{3,MR} = 0{,}0405$; $\alpha_{CR,MR} = 0{,}0494$, $\beta_{CR,\ MR} = 0{,}0137$ and $\gamma_{CR,MR} = 0{,}0014$ (Table 5).

For SSs of poly technological specialization in general with a more complex production structure and higher capacity the values of the partial OTC indicators are not lower. For example, if for variant III of the production structure of the SS of poly technological specialization in general $\alpha_{3,CR} = 0{,}00041$, $\beta_{3,CR} = 0{,}00177$ i $\gamma_{3,CR} = 0{,}00031$; $\alpha_{3,MR} = 0{,}002415$, $\beta_{3,MR} = 0{,}09377$ and $\gamma_{3,MR} = 0{,}01646$; $\alpha_{CR,MR} = 0{,}00805$, $\beta_{CR,\ MR} = 0{,}00591$ and $\gamma_{CR,MR} = 0{,}00104$; then for variant V of the production structure of the SS of poly technological specialization in general – $\alpha_{3,CR} =$ $=0{,}00819$, $\beta_{3,CR} = 0{,}01768$ and $\gamma_{3,CR} = 0{,}00291$; $\alpha_{3,MR} =$ $=0{,}12749$, $\beta_{3,MR} = 0{,}46084$ and $\gamma_{3,MR} = 0{,}07589$; $\alpha_{CR,MR} =$ $=0{,}01192$, $\beta_{CR,\ MR} = 0{,}0184$ and $\gamma_{CR,MR} = 0{,}00303$ (Table 5).

The highest partial compatibility takes place for TPs of the third line maintenance and the third line maintenance BMR of KhTZ-3522 tractors in the joint technological flow (Table 5).

Table 4. The results of calculation of values of indexes of complete OTC of all three different types of third line maintenance of KhTZ-3522 tractors for service stations (SSs) with different production structure and capacity from parametric series

№ of SS	Annual capacity Q_A, orders: $Q_{A\ max}$ for third line maintenance	Annual capacity Q_A, orders: $Q_{A\ min}$ for third line maintenance before MR	Amount of equipment and tools*, pcs.: K_{r1}	K_{r6}	K_{r7}	Number of posts f, units	Number of workers u, persons	Indexes of OTC: α	β**	γ
I	229	110	1	1	1	1	1	1	1	0,4954
	440	216					2	1	1	0,3762
	589	314					3	1	1	0,3015
	625	361					4	1	1	0,2232
	625	372					5	0,9932	0,9983	0,1242
	625	375					6	0,5684	0,6955	0,0402
	for first service station in general							**0,99631**	**0,99758**	**0,25999**
II	229	110	4	2	2	1	1	1	1	0,4454
	458	220					2	1	1	0,3428
	638	328					3	1	1	0,2873
	694	390					4	1	1	0,2292
	694	485					5	0,9904	0,9971	0,1342
	694	490					6	0,8690	0,9220	0,0735
	for second service station in general							**0,99678**	**0,9979**	**0,1976**
III	229	110	4	2	2	2	1	1	1	0,3642
	464	222					2	1	1	0,2809
	696	332					3	1	1	0,2441
	936	443					4	1	1	0,2344
	1118	543					5	0,9981	0,9991	0,2223
	1254	634					6	0,9701	0,9747	0,1952
	1335	699					7	0,9212	0,9037	0,1540
	1408	744					8	0,8701	0,7826	0,1109
	1408	766					9	0,8030	0,5688	0,0561
	1408	778					10	0,4150	0,1831	0,0147
	for third service station in general							**0,9674**	**0,8986**	**0,1577**
IV	229	110	4	2	2	3	1	1	1	0,3642
	471	223					2	1	1	0,2829
	704	334					3	1	1	0,2472
	932	444					4	1	1	0,2343
	1156	554					5	0,9955	0,9979	0,2252
	1344	657					6	0,9420	0,9578	0,2037
	1533 ^{opt}	747					7	0,8449	0,8656	0,17
	1656	831					8	0,7695	0,7414	0,1252
	1725	884					9	0,7058	0,5618	0,0796
	1815	932					10	0,6490	0,3331	0,0411
	1815	945					11	0,4642	0,1173	0,0138
	1815	953					12	0,0647	0,0069	0,0010
	for fourth service station in general							**0,9087**	**0,7471**	**0,1306**
V	229	110	4	2	2	4	1	1	1	0,2609
	472	224					2	1	1	0,1999
	706	335					3	1	1	0,1769
	936	446					4	1	1	0,1728
	1169	559					5	0,9941	0,9949	0,1728
	1389	659					6	0,9227	0,9209	0,1617
	1580	761					7	0,8254	0,7974	0,1315
	1739	866					8	0,7384	0,6456	0,0966
	1934	900					9	0,6347	0,4516	0,0646
	2070	958					10	0,5801	0,2235	0,029
	2178	976					11	0,469	0,0763	0,0105
	2250	985					12	0,1266	0,0095	0,0016
	2325	1009					13	0,0141	0,0029	0,0006
	2379	1029					14	0,0121	0,0038	0,0009
	for fifth service station in general							**0,8524**	**0,5031**	**0,0829**

* Amount of another equipment and tools: $K_{r2} = K_{r3} = K_{r4} = K_{r5} = K_{r8} = K_{r9} = \ldots = K_{r25} = K_{r26} = 1$ pcs.

β** – criterion for substantiation of specialization; - the result of substantiation of specialization

Table 5. The results of calculation of values of indexes of partial organizational and technological compatibility (OTC) of all different types of third maintenance of KhTZ-3522 tractors for service stations (SSs) with different production structure and capacity from parametric series

№ of SS	**Annual capacity Q_A, orders**		**Indexes of partial organizational and technological compatibility (OTC) of the technological processes of the two different third line maintenances:**								
	$Q_{A\ max}$	**$Q_{A\ min}$**	third line and third line before current repair (BCR)			third line and third line before major repair (BMR)			third line BCR and third line BMR		
			α	β*	γ	α	β*	γ	α	β*	γ
I	229	110	0	0	0	0	0	0	0	0	0
	440	216	0	0	0	0	0	0	0	0	0
	589	314	0	0	0	0	0	0	0	0	0
	625	361	0	0	0	0	0	0	0	0	0
	625	372	0	0	0	0	0	0	0,0068	0,0017	0,0002
	625	375	0	0	0	0	0	0	0,4316	0,3045	0,0176
	for first SS in general		**0**	**0**	**0**	**0**	**0**	**0**	**0,00369**	**0,00242**	**0,00063**
II	229	110	0	0	0	0	0	0	0	0	0
	458	220	0	0	0	0	0	0	0	0	0
	638	328	0	0	0	0	0	0	0	0	0
	694	390	0	0	0	0	0	0	0	0	0
	694	485	0	0	0	0	0	0	0,0096	0,0029	0,0004
	694	490	0	0	0	0	0	0	0,1310	0,078	0,0062
	for second SS in general		**0**	**0**	**0**	**0**	**0**	**0**	**0,00322**	**0,00206**	**0,00041**
III	229	110	0	0	0	0	0	0	0	0	0
	464	222	0	0	0	0	0	0	0	0	0
	696	332	0	0	0	0	0	0	0	0	0
	936	443	0	0	0	0	0	0	0	0	0
	1118	543	0,0001	≈0	≈0	0,0019	0,0009	0,0002	0	0	0
	1254	634	0,0008	0,0007	0,0001	0,0291	0,0246	0,0049	0	0	0
	1335	699	0,0014	0,0021	0,0004	0,0774	0,0943	0,0161	0	0	0
	1408	744	0,0019	0,0040	0,0006	0,1280	0,2134	0,0302	0	0	0
	1408	766	0,0019	0,0069	0,0007	0,1457	0,4106	0,0405	0,0494	0,0137	0,0014
	1408	778	0,0019	0,0096	0,0008	0,1547	0,6190	0,0496	0,4284	0,1883	0,0151
	for third SS in general		**0,00041**	**0,00177**	**0,00031**	**0,02415**	**0,09377**	**0,01646**	**0,00805**	**0,00591**	**0,00104**
IV	229	110	0	0	0	0	0	0	0	0	0
	471	223	0	0	0	0	0	0	0	0	0
	704	334	0	0	0	0	0	0	0	0	0
	932	444	0	0	0	0	0	0	0	0	0
	1156	554	0,0001	0,0001	≈0	0,0044	0,0020	0,0004	0	0	0
	1344	657	0,0011	0,0009	0,0002	0,0569	0,0412	0,0088	0	0	0
	1533 opt	747	0,0018	0,0022	0,0004	0,1534	0,1322	0,0260	0	0	0
	1656	831	0,0019	0,0034	0,0006	0,2286	0,2552	0,0431	0	0	0
	1725	884	0,0019	0,0047	0,0007	0,2923	0,4336	0,0614	0	0	0
	1815	932	0,0019	0,0060	0,0007	0,3490	0,6609	0,0815	0,0001	≈0	≈0
	1815	945	0,0477	0,0155	0,0018	0,3822	0,8456	0,0997	0,1060	0,0216	0,0025
	1815	953	0,0826	0,0309	0,0044	0,4508	0,8332	0,1176	0,4019	0,1290	0,0182
	for fourth SS in general		**0,00202**	**0,00361**	**0,00063**	**0,08447**	**0,24539**	**0,0429**	**0,00485**	**0,00395**	**0,00069**
V	229	110	0	0	0	0	0	0	0	0	0
	472	224	0	0	0	0	0	0	0	0	0
	706	335	0	0	0	0	0	0	0	0	0
	936	446	0	0	0	0	0	0	0	0	0
	1169	559	0,0002	0,0002	≈0	0,0057	0,0050	0,0009	0	0	0
	1389	659	0,0013	0,0016	0,0003	0,0760	0,0776	0,0136	0	0	0
	1580	761	0,0018	0,0030	0,0005	0,1728	0,1996	0,0329	0	0	0
	1739	866	0,0019	0,0041	0,0006	0,2597	0,3503	0,0524	0	0	0
	1934	900	0,0020	0,0051	0,0007	0,3633	0,5432	0,0778	0	0	0
	2070	958	0,0019	0,0061	0,0008	0,4180	0,7704	0,1001	0	0	0
	2178	976	0,0376	0,0187	0,0026	0,4846	0,9035	0,1245	0,0089	0,0015	0,0002
	2250	985	0,1195	0,0430	0,0071	0,5587	0,9036	0,1498	0,1952	0,0440	0,0073
	2325	1009	0,1358	0,0614	0,0124	0,6045	0,8586	0,1739	0,2456	0,0772	0,0156
	2379	1029	0,1339	0,0658	0,0153	0,6335	0,8449	0,1964	0,2205	0,0854	0,0199
	for fifth SS in general		**0,00819**	**0,01768**	**0,00291**	**0,12749**	**0,46084**	**0,07589**	**0,01192**	**0,01841**	**0,00303**

β* – criterion for substantiation of specialization; - the result of substantiation of specialization

In real terms, the assumption, that any values of the annual program $W_{A\ \min}$ (by the annual number of orders for the third line maintenance BMR) are equally probable, is usually not true, because the SSs with a more complex production structure mainly work generally in a range of values of annual programs of orders for all three different types of third line maintenance of KhTZ-3522 tractors, in which a high enough level to use their production facilities be achieved. However, in such a range of values of annual program of orders, predominantly partial compatibility of TPs of the third line maintenance and of the third line maintenance before main repair (BMR) in the joint flow takes place. For example, for variant IV of the production structure of the SS, when the annual number of orders for maintenance of KhTZ-3522 tractors meets the condition $W_{A\ \min} > 884$, when 10, 11 or 12 workers work (u = 10 persons, u = 11 persons or u = 12 persons), then $\beta_{3,MR} > 0{,}5$. Similarly, for variant V of the production structure of the SS, when the annual number of orders for maintenance of KhTZ-3522 tractors meets the condition $W_{A\ \min} > 866$, when 8, 9, 10, 11, 12, 13 or 14 workers work (u = 8 persons, u = 9 persons, u = 10 persons, u = 11 persons, u = 12 persons, u = 13 persons or u = 14 persons), then also $\beta_{3,MR} > 0{,}5$.

CONCLUSIONS

1. The formed parametric series of production facilities of service stations for maintenance of KhTZ-3522 tractors both mono- and poly technological specialization (Tables 1–3) are the basis for the choice of the effective design solutions with taking into account, firstly, the forecast of annual changes in the total number of maintenance orders due to the changes in the number of these tractors in the service area, and, secondly, the prediction of seasonal fluctuations in the flow of orders due to the objective variation of use of these tractors in agriculture.
2. At the same time, the obtained values of complete OTC indicators of the TPs of all three types of third line maintenance of KhTZ-3522 tractors in the joint flow for variants I, II and III of production structure of SSs designate the expediency of their poly technological specialization.
3. The obtained values of complete and partial OTC indicators of the TPs of all three types of third line maintenance of KhTZ-3522 tractors in the joint flow for variants IV and V of production structures of SSs indicate that additional research involving the simulation of the process of formation of orders for maintenance of KhTZ-3522 tractors in the region is needed to substantiate their specialization.

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ОРГАНИЗАЦИОННО-ТЕХНОЛОГИЧЕСКАЯ СОВМЕСТИМОСТЬ ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССОВ ТРЕХ РАЗЛИЧНЫХ ТИПОВ ТРЕТЬЕГО ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ ТРАКТОРОВ ХТЗ-3522 В ЕДИНОМ ТЕХНОЛОГИЧЕСКОМ ПОТОКЕ

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Аннотация. На основании результатов структурно-параметрического анализа и синтеза трёх различных видов третьего технического обслуживания (ТО-3) тракторов ХТЗ-3522 с использованием теории графов и расписаний обоснованы параметрические ряды производственных структур пунктов технического обслуживания этих тракторов как моно-, так и поли-технологической специализации различной производительности. Исследована организационно-технологическая совместимость технологических процессов трёх различных видов ТО-3 тракторов ХТЗ в едином технологическом потоке. Получены и проанализированы зависимости показателей полной и частичной организационно-технологической совместимости этих процессов от значения годовой программы наиболее сложного и трудоемкого ТО-3 перед капитальным ремонтом. Приведены результаты расчётов показатели полной и частичной организационно-технологической совместимости технологических процессов всех трёх различных видов ТО-3 тракторов ХТЗ-3522 в едином технологическом потоке в целом для пунктов технического обслуживания с различной производственной структурой и производственной мощностью. Наивысшие значения показателей частичной организационно-технологической совместимости получены для технологических процессов ТО-3 и ТО-3 перед капитальным ремонтом. Высокие значения показателей полной организационно-технологической совместимости технологических процессов всех трёх различных видов ТО-3 этих тракторов в едином технологическом потоке, полученные для всех пяти вариантов производственных структур пунктов технического обслуживания тракторов ХТЗ-3522 различной производственной мощности, являются предпосылкой использования поли технологической специализации.

Ключевые слова: трактора ХТЗ-3522, техническое обслуживание, технологические процессы, организационно-технологическая совместимость, пункты технического обслуживания, специализация.