STATISTICAL ANALYSIS OF THE PROCESS OF REPAIR OF AUTOMOTIVE VEHICLES USING METHODS OF CPM AND PERT NETWORK ANALYSIS

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Abstract: The aim of the article was to present the results of statistical analysis of the ability of the process of repairing motor vehicles in the Polish dealer network. The article presents the results of research carried out on a sample of six organizations. In empirical proceedings, the following research methods were used: literature review, analysis of secondary research, observation, statistical analysis of process capability and network analysis methods. The second point presents the assumptions of statistical analysis of the process capability. Then, the structure of empirical proceedings was described. In the third point, the results of the basic empirical study were characterized. The next point of the article presents the results of the analysis of the process capability of the studied process using the CPM and PERT methods.

Keywords: process improvement, process quality, SPC, CPM, PERT.

1. Introduction

The dynamic market environment of dealerships functioning in the field of after-sales services of the automotive sector is determined by the development of car production technology, the implementation of new tools enabling their diagnosis and repair, and an attempt to meet the prosumer's expectations in terms of the quality of repair services. This means that in the discussed issue the quality of the repair process is a factor that can be a source of competitive advantage (Dekimpe, Steenkamp, Mellens, and Abeele, 1997). More precisely, quality is both an overall assessment of the organization's functioning and one of the measures of competitive advantage (Ząbek, 2013). Clients in choosing an authorized dealership are guided by such motives as: brand recommendations, own experience with an authorized dealership and positive opinions about a given brand in the media (Ząbek, 2014). In addition, it should be emphasized that the quality of repair is one of the most frequently used measures to assess the mega-process of after-sales service (Sliż, 2016). More precisely, the quality of the repair process can be an important element of competitive advantage between authorized dealerships, which in the current market realities compete on the market in the space of business processes. The article attempts to assess the quality of the repair process using statistical control of process capability and network programming methods.

2. Statistical analysis of the process capability

The purpose of process capability analysis is to evaluate the process flow due to the specified tolerance interval. The capability of process (Cp) indicator enables the assessment and improvement of quality (Juran, 1991, p. 81-85.) and the efficiency of the process of products and services produced (English, Taylor, 1993). According to A. V. Feigenbaum, the process capability functions in the area of Total Quality Management (TQM) and it is also presented as one of the strategic management techniques. In summary, the process has the capability "if its distribution is between the upper [(UCL] and lower tolerance limit [(LCL)], while the difference must be greater than six standard deviations resulting from the variability of the given process" (Grajewski, 2007, p. 113). By extending the parameters and elements of the Cp index, three possible cases of the result obtained can be characterized. Here they are: $6Df < (UCL - LCL)$ – process is capable, $6Df = (UCL - LCL)$ – the actual distribution range is exactly within the tolerance range and $6Df > (UCL - LCL)$ – the process is incapable (Stefanów, 2013, pp. 193-194). In addition, when analysing the process capability, attention should be paid to the position indicator of the average value of the Cpk parameter distribution. According to J. Szkoda, this indicator "is the measure of the distance between the actual value of the average distribution $- \bar{X}$ and the middle tolerance interval (Szkoda, 2002, p. 90).

The reasons for the variability of the process were characterized by P. Grajewski. These are: systemic causes, special causes and improper determination of tolerance limits at the process design stage (Grajewski, 2007, p. 112-113). In further detail, it is also necessary to indicate the causes of disturbances in the process of natural nature, resulting from the natural nature of the process variability. Unlike system sources, it is impossible to completely reduce them (Hamrol, Kujawińska, 2006, p. 149).

3. Analysis of the diagnosis, verification and repair process capability

Structure of empirical proceedings

The empirical study was carried out in the years 2015-2016 on a non-stabilized sample of six Polish authorized dealerships (targeted choice). At this point, it should be emphasized that only organizations classified at the minimum third level of process maturity participated in the study. The selection of the organization was conditioned by the respondents' declaration that the processes in the units surveyed were identified, formalized and metered (Sliż, 2016). In the surveyed units, only warranty repairs were analysed, selected for further analysis by probabilistic technique. The number of repairs tested was determined by the size of the organization, identified as the total number of repairs per year. Repair measurements were made using the repair effectiveness indicator, expressed as the ratio of the normative repair time specified in the manufacturer's technical documentation to the real time, understood as the difference between the date and time of completion of the workshop activities and the date and time of its commencement.

Determination of tolerance limits and measurement results of the tested process

On the basis of car manufacturers' recommendations and applied practices in the tested units, the tolerance limits and the nominal value of the parameter were set (Table 1). Measurement results forms based on the concept of J. Szkoda were used (Szkoda, 2002, p. 94) to carry out the measurements. The results of this part of the study are presented in table 1.

Table 1.
The form for measuring the results of the process capability in the organization

Analysis of the process qualitative capability							
Input data							
Process name				Diagnosis, verification and repair			
Service name				Mechanical repair			
Nominal value of the parameter				1,0			
Parameter tolerance				UCL = 1,2; LCL = 0,8			
Measurement result for ASO_1 C_01							
0,62500	0,83636	0,73333	1,02222	0,72500	1,69412	0,96000	1,02857
1,20000	0,60000	1,20000	0,66316	0,95000	1,40000	0,53333	0,40000
1,50000	0,60000	0,75000	0,60000	1,02000	0,70000	1,02857	0,00000
0,93333	1,80000	1,40000	0,80000	0,46667	0,40000	0,86667	1,38000
Measurement result for ASO_2 C_02							
1,58571	0,70000	1,40000	0,25000	0,00000	0,70000	0,60000	-
Measurement result for ASO_3 C_04							
0,20000	0,80000	0,80000	0,51250	0,35000	1,20000	0,40000	0,97500
1,20000	0,31667	0,90000	0,82000	0,30000	0,70000	0,68333	0,66500
0,46667	0,49091	0,66667	0,72500	0,50000	0,50000	0,96667	1,20000
0,66667	-	-	-	-	-	-	-

Measurement result for ASO_4 C_07							
1,73333	0,00000	0,60000	0,88235	1,50000	0,80000	0,80000	0,60000
0,80000	0,20000	1,50000	0,80000	0,22857	1,80000	0,60000	0,17778
0,80000	0,60000	2,20000	0,00000	1,13333	1,20000	0,65000	1,10000
0,30000	1,91111	0,72000	1,60000	2,10000	0,90000	0,93333	0,60000
0,80000	0,84000	0,28571	0,73585	0,75000	1,45000	1,28182	0,85714
0,28235	0,96000	1,20000	0,40000	0,92308	1,80000	0,45000	0,36923
1,08000	-	-	-	-	-	-	-
Measurement result for ASO_5 P_06							
0,00000	1,30000	0,40000	1,20000	0,70000	3,60000	2,40000	1,20000
1,70000	3,00000	0,74286	-	-	-	-	-

Source: based on own study.

In the surveyed group of organizations, it was noted that the value of the indicator for all units indicates the inability of the process, i.e. Cp < 1 (Table 2).

Table 2.
Capacity and performance indicators for fixed tolerance limits 0,8 and 1,2 and N = 1,0

Variable	Capacity and performance indicators for all variables				
	Cp	Cr	Cpk	Cpl	Cpu
ASO_1C_01	0,157	6,387	0,079	0,079	0,234
ASO_2C_02	0,119	8,388	-0,031	-0,031	0,269
ASO_3C_04	0,228	4,385	-0,137	-0,137	0,593
ASO_4C_07	0,111	8,988	0,057	0,057	0,165
ASO_5P_06	0,059	17,092	-0,081	0,198	-0,081

Source: based on own study.

The obtained values of the Cp indicator may indicate a large spread of the process. Interpreting the received values of Cp and Cpk indicators for the variables ASO_1, ASO_4 and ASO_5, the conclusions with a large scale of the process was formulated.

Table 3 presents the values of Cp, Cr, Cpk, Cpl and Cpu indicators for the modified tolerance field.

Table 3.
Process capacity indicators for the tested variables for tolerance limits 0,8 and 1,4 and N = 1,0

Variable	Nominal value and parameter tolerance	Capacity and performance indicators for all variables				
		Cp	Cr	Cpk	Cpl	Cpu
ASO_1	*LCL= 0,8, UCL= 1,4 i N = 1,0*	0,234	4,258	0,078	0,079	0,391
ASO_2		0,179	5,592	-0,031	-0,031	0,389
ASO_3		0,342	2,923	-0,136	-0,136	0,821
ASO_4		0,167	5,992	0,057	0,057	0,277
ASO_5		0,088	11,394	-0,022	0,198	-0,022
ASO_1	*LCL = 0,6, UCL = 1,2 i N = 1,0*	0,179	5,592	0,088	0,088	0,269
ASO_2		0,235	4,258	0,234	0,235	0,234
ASO_3		0,342	2,923	0,091	0,091	0,593
ASO_4		0,167	5,992	0,165	0,168	0,165
ASO_5		0,088	11,394	-0,081	0,256	-0,081

Source: based on own study.

Analysis of the repair process capability on the example of modification of the cooling system fan – supplementary test

Analysing the results obtained in point 3.2. of this article, it was concluded that the heterogenous character of repairs could have a significant impact on the ability of the process being tested. This means that in the discussed environment they were different due to: the structure of activities, the model of the car, the type of the drive unit, the nature of the fault and the time necessary to verify it. On this basis, a homogenous service with a limited potential of external influences was selected, for which the time of verification of the defect, the availability of specialized tools or the waiting time for the solution of the manufacturer's technical platform were qualified. The supplementary test was carried out at an additional authorized dealership (ASO_6) based on 34 completed mechanical repairs involving the modification of the fan cooling system of the drive unit. As a consequence, a review of repair orders and supplementary documentation from the twelve-month period was carried out. The results of the subject's ability, for different tolerance limits, were presented in the form of a radar graph (Figure 1).

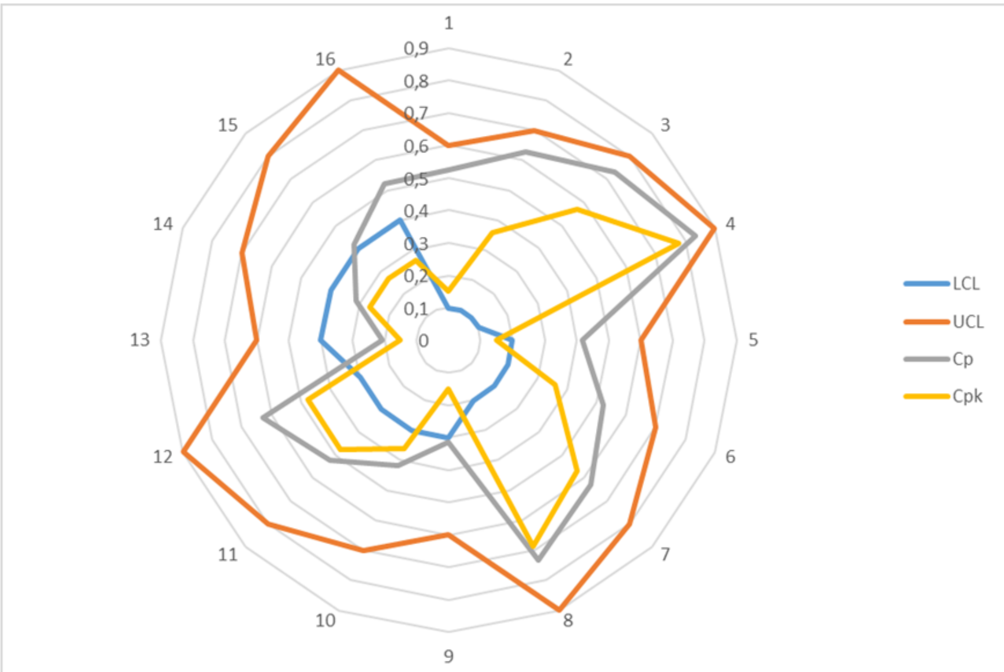

Figure 1. Comparison of the Cp and Cpk indicators values tested cooling system repair process in a passenger car. Based on own study.

At this point, it should be noted that in addition to the amount of technological surplus, experience of the mechanic and the routine of the works he has acquired, there are no additional, significant premises differentiating the process under investigation.

In order to assess the impact of the repetition of the activities carried out on the process capacity, the repairs were systematized in a time series (Figure 2).

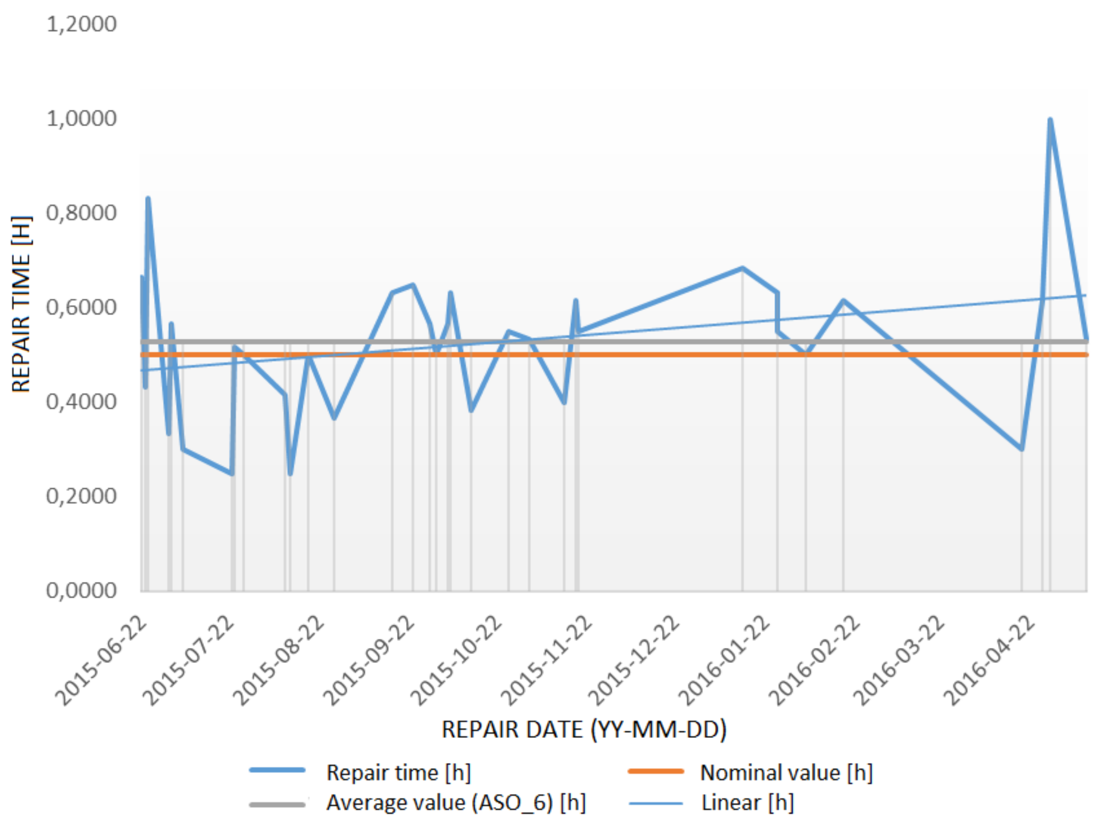

Figure 2. Characteristics of the length of modification time of the fan cooling system of the drive unit in the P_ASO_6 unit from 22.06.2015 to 22.04.2016. Based on own study.

On the basis of the graph presented in figure 2, the conclusion was drawn that the repetitiveness of the repair in the examined unit did not have a positive effect on shortening or standardizing the time of its implementation. An important aspect in the discussed problem can be considered the fact that the repairs were carried out by various mechanics. As a consequence, an attempt was made to analyse the repairs under examination, detailing the employees who implemented them. As a result, the tolerance limits were set, including the mechanic, whose average duration of repairs was closest to the nominal value. On this basis, values C_p= 0,27 and C_{pk} = 0,21 were obtained, indicating a lack of statistical capability of the studied course.

4. Methodology of CPM and PERT in the statistical assessment of the diagnosis, verification and repair process capability

In order to characterize the activities in the discussed process in detail, the network analysis methods – CPM and PERT – were used. Activities $A - L$ were assigned according to the attribute, which was their duration (Table 4).

Table 4.
Summary and characteristics of times for activities A−L

Activity	Characteristics of the activity	Immediately preceding action	Times*			Expected time t_e
			a	*M*	*b*	
A	Disconnecting the battery	-	0,02	0,03	0,05	0,0317
B	Disassembling the air intake flange	-	0,02	0,03	0,05	0,0317
C	Disassembling the screw securing the cooling fan	B	0,01	0,02	0,02	0,0183
D	Moving the cooling fan towards the drive unit	C	0,01	0,04	0,05	0,0367
E	Installation of temporary cooling system cooler protection	D	0,02	0,04	0,07	0,0417
F	Removal of the material surplus from the cooling fan casing	E	0,05	0,1	0,3	0,1250
G	Clearance of the space on which the E operation was performed	F	0,03	0,07	0,2	0,0850
H	Disassembly of the radiator cooler protection	E	0,03	0,04	0,06	0,0417
I	Installation of the cooling system fan as a result of the B operation	H	0,03	0,05	0,1	0,0550
J	Installation of the screws that fix the cooling fan	C, I	0,01	0,02	0,03	0,0200
K	Installation of the air intake flange	J	0,01	0,03	0,04	0,0283
L	Connecting the battery	A, K	0,01	0,03	0,03	0,0267

Note: the preceding activity is understood as an activity completed in order to start a given activity *a* – optimistic time, *b* – pessimistic time, *m* – the most probable time. Based on own study.

The AoA (Activity on Arrow) graphs presented in figures 3-4 were built taking into account the course of the process in accordance with the technical documentation of the repair. Analysing the network diagram presented in figure 1, two critical paths were identified, the first one: B – C – E – D – H – I – J – K – L and the second one: B – C – D – E – F – G.

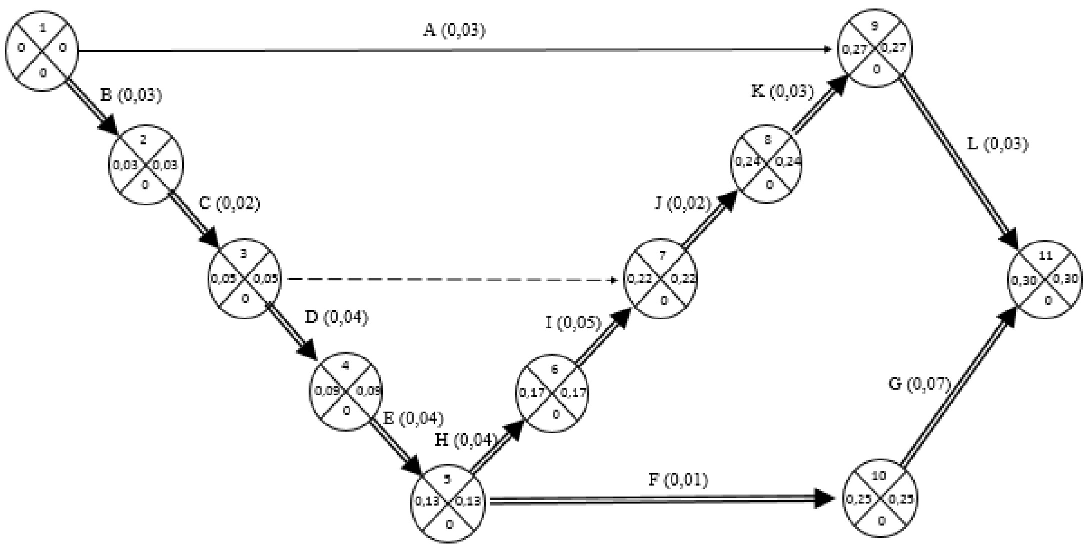

Figure 3. CPM network diagram for modifying the fan cooling system of the drive unit. Based on own study.

On this basis, it can be clarified that the acceleration of one of the series of activities will not positively affect their improvement, because the second series determines the duration of the entire operation. In addition, the time of two critical paths is close to each other and amounts to 0.3 hours. This means that in order to reduce the total time, both series should be modified. Based on the CPM network graph (Figure 3) the LCL and UCL values were defined, respectively: time *a* = 0,25 and *b* = 1,0 (Table 4). For the selected tolerance limits, the value obtained was C_p = 0,79, and C_{pk} = 0,59. The second variant of the assessment provided for an analysis taking into account the critical time = 0,3 (LCL) and the longest possible duration of activity *b* = 1,0 (UCL). For the accepted tolerance limits, the value C_p = 0,74, while C_{pk} = 0,45. On this basis, it can be assumed that using the CPM method, tolerance limits should be interpreted, referring their values to optimistic and pessimistic times. Then, an attempt was made to determine the critical time as the nominal value, while setting the tolerance range from 0.25 to 1.0. The value of the C_p indicator for such parameters was 0.79, and C_{pk} = 0.59. Analysing the studied process, it was found that in addition to its statistical inability, the process is also incorrectly centres, as well as the fact that the average value of the studied variable *repair time* (0,53) does not coincide with its nominal value (0.5).

In turn, Figure 4 presents a network of dependencies of actions aimed at carrying out the discussed mechanical repair using the PERT method. On the PERT network graph, one can identify the critical path B – C – D – E – F − G (Figure 4). The obtained critical time value, for μ = 0,34 suggested that a given activity can be performed for a shorter time than during the fixed nominal value.

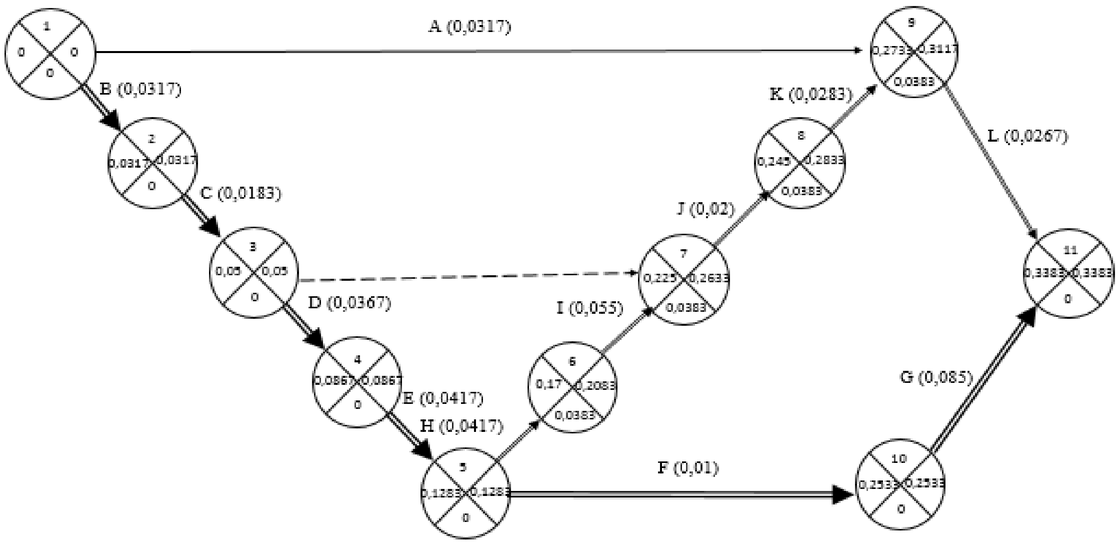

Figure 4. The PERT network graph for fan modification of the cooling system of the drive unit. Based on own study.

Therefore, using this quantity in the statistical assessment of process capacity, it was taken as the value of the lower tolerance limit. In turn, the upper limit of tolerance was defined by the sum of expected times (0.54). As a result of such a determined range, at the nominal value (0.5 [h]), the value C_p= 0.7 and C_{pk} = 0.4 was obtained.

5. Summary

On the basis of the statistical analysis of the capacity of the repair process and the observations carried out in the examined units, it was concluded that in the examined objects there were so-called hidden and parallel factories, "(...) that is, the unrecorded operating system of the organization [consisting of processes and systems used to correct errors" (Grajewski, 2016, p. 120). On the basis of the obtained results, they qualified for: extended waiting time of the mechanic to release the stock from the warehouse, multiple cataloguing of parts necessary to perform the repair, assigning repair orders to unqualified mechanics, repeated inspection activities and duplicate technical documentation verifications for the same repair. In addition, it should be emphasized that the data obtained regarding the duration of repairs were supplemented manually by mechanics. None of the units qualified for observation monitored the working time using an analogue or digital time recorder for the implementation of activities. Despite the verification of the quality of the data obtained, it should be noted that the possibility of irregularities in the records of the duration of activities was taken into account.

In conclusion, the results obtained in the article may be an incentive to set a further direction of research in the evaluation of after-sales processes of the automotive sector, using a combination of statistical methods of process capacity analysis and networking programming.

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