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An Empirical Study of the Variables Affecting the Frequency of Engine Oil Change in the Environmental Aspect

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1. Introduction

In recent years, activities in the road transport segment have focused on various aspects of reducing its harmful environmental impacts. This results both from the global trend related to the fight against global warming, as well as from activities aimed at reducing the use of oil resources. The transport sector is responsible for a significant proportion of air emissions, which directly and indirectly affect people, climate and ecosystems. Moreover, the limited oil reserves have an influence on socio-political and economic relations (Knez et al., 2014). There are a lot of studies related to the reduction of exhaust emissions (CO_2 reduction) in the transport sector (Aditjandra et al., 2016; Kumar Pathak et al., 2016; McBain et al., 2018), and the fuel consumption of vehicles (Matas et al., 2017). There are also several studies on the impact of motor oils, especially low viscosity oils on reducing fuel consumption and CO_2 emissions (Macián et al., 2014, 2015), whereas there is a very limited number of studies concerning the protection of the environment from harmful effects of operating fluids.

Environmental protection activities are an important aspect of almost every area of life and therefore are also vital in the context of waste oils. Transport and industry consume large amounts of lubricant oils, a lot of which later become waste oils. Waste lubricant oil (WLO) is produced in automotive, aviation, marine and industrial sectors but the most significant one (56%) is the automotive sector (IETC, 2013; Osman et al., 2017). In many countries, including Poland, waste oils are considered harmful. They constitute one of the main streams of hazardous waste in Europe and contain many toxic and carcinogenic substances, such as: polycyclic aromatic hydrocarbons (PAHs), products of hydrocarbons oxidation and thermal decomposition, sulphur, phosphor, chlorine and nitrogen compounds, metal derivatives that come from oil additives, products of wear of machinery as well as contaminants from the environment and sometimes also polychlorinated biphenyls (PCB) (Fuentes et al., 2007; Zając et al., 2015). These compounds may cause environmental damage if not properly disposed of and purified (Pelitli et al., 2017; Pinheiro et al., 2017). In their paper, Ramadass et al. confirmed the higher toxity of the used engine oil, compared with fresh oil, based on the tested toxicity parameters (among others activities of soil dehydrogenase and earthworm survival) (Ramadass et al., 2015). Mameli and marletto also indicated used oil as the waste materials which need to be adequately disposed, because of its harmful environmental impact (Mameli & Marletto, 2014).

It is assessed that only 40% of the 45 million tons of the generated waste oil (per year) is gathered and disposed of properly and about 8% is recycled into new lubricant oils (Fuentes et al., 2007; IETC, 2013; Osman et al., 2017). The remaining 60% is discarded (Zhang et al., 2017). In accordance with the guidelines contained in the European Directive 75/439/EEC on the disposal of waste oil, the priority in the management of waste oils has regeneration process (Pinheiro et al., 2017). As much as 19% of the total amount of lubricants available on the market is used in the EU countries. In 2015, around 6.8 million tons of lubricants were used in the EU, while EU handles annually around 3 million tons of WLO (Pinheiro et al., 2017). The resulting difference (around 50%) is due to the fact that part of the oils is irretrievably lost during use (combustion in a combustion chamber, evaporation, leaks, residue in containers, etc.).

Life-cycle of lubricants in industry supply chains and their handling is more and more often considered an important element of good management of environmental issues by suppliers as well as their clients (Guerin, 2008). The degree of the environmental impact of engine oils depends primarily on their chemical composition, production process, distribution and application. The hazard caused by engine oils is caused by a high content of additives resulting from growing expectations as to the quality of oils and by longer periods of use of modern lubricants that lead to the accumulation of harmful substances. On the one hand, trying to prolong the periods of engine oil use leads to a rise in the content of additives (so as to increase viscosity, inhibit oxidation, etc.) and, as a result, also in the content of toxic substances in the oils but, on the other hand, decreases the frequency of oil changes hence reducing its total use. As a result, the amount of waste is lower but the content of harmful substances is higher.

What is considered a serious environmental problem is a significant dispersal of oils resulting from a big number of drivers who use only slight amounts of oils. The usual amount of oil used in an engine of a passenger car is between 4-8 dm^3 (4-50 dm^3 in the case of lorries and machinery). After a certain period, the oil is changed and fresh one is applied. The procedures of handling of the used oil are varied. In the case of passenger cars, oil change takes place at a service station and the used oil is collected by car maintenance companies. More and more frequently, the engine oil and oil strainer change services are included in the price of the products, which encourages car owners to have the oil changed at service stations.

What strongly influences the amount of waste produced is the user awareness. The generally recognized criteria of engine oil change in passenger cars, which are: mileage and oil change schedules based on average figures for different vehicles, are not always sufficient for an adequate approximation of the level oil consumption (Kral et al., 2014; Sejkorová et al., 2017). The frequency of oil change is primarily dependent on the recommendations of the manufacturer. Based on the engine construction, its working parameters and the intended purpose, an oil of appropriate viscosity and performance is chosen. Modern cars are fitted with on-board computers with software that keeps engine performance statistics. It counts not only the mileage but also the number of start-ups, the average speed, trip times, etc. Having collected the data, the software estimates the oil change intervals. However, it should be noted that the intervals are estimated based on certain algorithms which do not necessarily reflect real engine operating conditions and hence do not guarantee optimal oil change time. Changing oil too early leads to an unjustified increase in oil consumption, and therefore to a greater environmental impact due to a bigger amount of waste. Waiting too long with the oil change leads to an increase wear of engine parts and to an excessive concentration of harmful products of degradation in the used oil, which can hinder the regeneration process and have adversely affect on the ecosystems. What is more, in both cases, a car user bears additional costs, either of purchasing the oil in the first case or repairing the worn parts in the second one (Basu et al., 2000; Jun et al., 2006). The aim of this study is to assess the behaviour of car users with regard to frequency of oil change, factors influencing oil change times, place of oil change as well as the need for oil top ups. Moreover, a thorough research has been done to establish a connection between the frequency of oil change and additional factors influencing the degree of oil degradation (car mileage, engine type and capacity as well as the conditions of use). The obtained results can have a positive inluence on the accuracy of assessment of car users' awareness as well as the course of action in terms of a reasonable choice of oil change time. The outcome of this study combined with the results from a thorough investigation regarding travel behaviour and enviornmental-transport policy conducted by Garcia-Sierra et al. can help to understand better why drivers behave as they do (Garcia-Sierra et al., 2015).

The paper is a part of research aiming to assess the awareness of car users in terms of engine oils use. The whole contributes to the existing literature by examining how citizen opinions (collected through a national survey) can be used to select a core set of indicators of monitoring the effectiveness of policies for sustainable management of used oils.

2. Methods and data

2.1. Poland

Poland is a country in Eastern Europe. It is the eleventh country in Europe in terms of area (312,679 km^2). As of 1st January 2018, the population of Poland amounts to nearly 38.5 million people. According to the Central Register of Vehicles, as of 8th June 2017, the number of vehicles registered in Poland amounts to 28,678,674 (including 22,005,578 cars and 3,203,256 lorries – the remaining part includes buses, motorcycles and mopeds). The number of vehicles registered in Poland for the first time in 2016 is 1,822,049 („Central Register of vehicles and drivers, www.cepik.gov.pl", 2018). This includes 26% (475,935) of new cars (lightweight vehicles – passenger cars and light commercial vehicles), which is around 3% of new lightweight vehicles registered in the EU (14.6 millions) (Pocketbook, 2017).

According to a report of the Polish Organisation of Oil Industry and Trade, in 2017 the Polish market of lubricant oils reached the level of 226,896 tonnes, which is a 1.62% y/y increase (POPiHN, 2017). Approximately 47.51% of all lubricant oils sold in Poland are oils for the automotive industry. Within the automotive segment, they account for around 80%. It is particularly worth pointing out that in 2017 the market share of synthetic oils for passenger cars grew from 5.5% in 2007 to 16.29%. Synthetic oils are presently mostly purchased by vehicle users.

2.2. Research framework

Two important aspects have to be taken into account with regard to oil change – firstly, proper engine protection should be provided and secondly, environmental concerns should be addressed. An optimal oil change time is when it is possible to maintain a balance between the two aspects, i.e. when the oil is changed before it loses its properties but not too early so as not to have an unnecessary negative impact on the environment.

Two vital aspects related to oil change have been included in the paper – the place of oil change and the details of use (urban / extra-urban driving). The place of oil change is very important as, when deciding to change oil on their own, car users choose oil based on viscosity classification and do not take into consideration other requirements. However, the choice of oil of certain viscosity class may not fulfil the requirements of a particular engine. The second aspect is concerned with obtaining responses from car users as to the percentage of city-driving. If the percentage is high (i.e. mostly short distances are covered) the engine cannot reach a proper operating temperature, and therefore the oil loses its properties faster. As a result, an increased degradation of engine oil occurs which intensifies the process of engine wear. Abas et al. noticed that engines of cars operating in urban areas work under part-load condition due to low or medium speeds and long idle periods (Abas et al., 2018).

2.3. The environmental protection

After the intended period of use, lubricant oils become waste. Oil waste is the main stream of dangerous waste in Europe. Waste lubricant oils can be further processed to obtain re-refined lubricant oils or they can be burned, in order to generate energy, in installations designed for this purpose. Currently, around 13% of all base oils used in the EU come from re-refined waste oil. Engine oils are the biggest group of lubricant oils in terms of generated waste, which is due to the number of vehicles in use as well as a significant degree of oil recovery. It is estimated that the recovery rate amounts to 52-86% and the remaining part of oil is lost in the process of evaporation, leaks, and combustion in the combustion chamber. Waste framework directive (2008/98/EC) is the main legislation of the EU regulating the handling of waste oils. The regulation determines and establishes inter alia the obligation to apply the waste hierarchy.

The amount of generated waste is strongly influenced by the frequency of oil changes performed by individual users. If an oil change is done too early, particularly when the oil's properties have not been lost yet, it not only leads to increased operating costs, but also to a greater burden on the environment.

From the point of view of environmental protection, the most beneficial way of handling waste oils is their collection and regeneration. However, it should be taken into account that within the stream of waste, there will be cases of informal waste management, that is burning of used oil in the place of collection or even releasing it directly to the environment. Apart from machinery breakdown and unforeseeable events, all the other hazards of polluting the environment with lubricants (oil systems leaks, improper storage, improper maintenance of machinery, deliberate release of oils to rivers and soil) can and should be limited or eliminated through strict compliance with the regulations and proper sealing of the oil systems.

2.4. Questionnaire design and distribution

The statistical study included a group of 1446 drivers from all over Poland. The study was conducted between 1st January and 31st July 2018 and the questionnaire method was used. The questionnaires were submitted online and required providing answers to all questions, which helped to avoid the problem of incomplete data in some questionnaires. The questionnaire included 21 questions – 15 closed-ended and 6 open-ended questions. The questionnaire was addressed to drivers who use fully synthetic engine oils. It was completed solely by drivers who decide or co-decide about the oil change. The study was conducted using probability sampling (random sampling), based on a nationwide, commercial database of drivers.

The formula that was used to determine "the sample size (n) in the estimation of the fraction of elements distinguished in the population" has the following form („Sample size calculator, www.raosoft.com/samplesize.html", 2018):

$$x = Z(\frac{c}{100})^2 r(100\text{-}r) \quad (1)$$

$$n = \frac{Nx}{((N-1)E^2+x)} \quad (2)$$

$$E = Sqrt[\frac{(N-n)x}{n(N-1)}] \quad (3)$$

where:
N – the population size,
r – the fraction of responses that you are interested in,
Z(c/100) – the critical value for the confidence level c.

The margin of error was set at 3.5%. The confidence level was set at 99%. The calculated sample size was 1354. In total, 1446 usable questionnaires were collected.

The questionnaire allowed for identification of the respondents' sex, age, type of the settlement where they live, as well as engine type and engine capacity in their cars, year of car production and car mileage. Moreover, the respondents were asked to stipulate the percentage share (0-100%) of city driving. As mentioned before, the paper is a part of research aiming to assess the awareness of car users in terms of engine oils use.

The authors of the study decided to use correspondence analysis (CA), as it is a descriptive and exploratory data analysis technique whereby results are presented as a bi-plot, i.e. a graphical method which allows for displaying points representing the first variable (rows) as well as the second variable (columns) on one figure. Analysis of their relative positions is subject to certain rules. The row and column coordinates are summarized in a single plot. If data are presented in such a way, the neighbourhood (or distance respectively) between observations and variables provides evidence for strong relationships (or weak relationships respectively). It is important to note that the relative positions of one point in one set should be interpreted with respect to all the points in the other set.

The basic result of correspondence analysis is a scatter diagram – a set of measures that serves to assess the quality of representation of a multidimensional space on a surface. Dimensions are typically plotted to visualize the degree of association between levels of the two categories of variables. In CA, this graphic presentation is called a “map”. The origin on the map represents the place where there is no difference among the profiles. The nearer a column(row) profile’s vector location is to the origin, the closer it is to the average profile.

The algebraic basis of CA is decomposition of a matrix that represents relations between rows and columns into singular vectors and singular values (singular value decomposition). The sum of the squares of singular values equals the so-called inertia, which is chi-square calculated for a given table, divided by a sample size (n). A given singular value squared allows to assess the proportion of inertia explained by a given dimension. The quality of displaying the correlations within a table on a lower number of dimensions allows to assess the share of inertia of a given dimension in the total inertia of a table.

In the subject literature, it is very difficult to find results of similar studies conducted in the EU. Studies concerning the preferences of drivers in terms of oils are usually commissioned by concerns that produce oils or editors of automotive magazines (for the target groups). The present study fills the gap in the subject literature.

3. Presentation and analysis of study results

3.1. Characteristics of the sample

Table 1 presents the demographic attribute of the sample. As the questionnaire referred to the oil industry, the questionnaire sample was skewed towards male respondents – very often common in literature (Peters et al., 2015). Younger Poles (20-30 years of age) were more inclined to take part in the study, which was compatible with other research conducted in the Polish context (Smol et al., 2018).

The selected sample had the following characteristics:

- 80% of the respondents were between 18 and 40 years old, with those between 20-30 years (50.2%) being dominant,
- 20% of respondents were older than 40,
- 52% of respondents had completed a higher education (bachelor’s or master’s degree),
- 26% of respondents had a secondary education, 17.7% of respondents indicated that they were in college,
- About 4% of respondents had basic education or relatively lower education levels.

Table 1. The demographic characteristics of the sample (n=1446)

Gender		**Age**	
Male	84.5%	20 and below	4.3%
Female	15.5%	21-30	50.2%
Not specified	–	31-40	25.7%
Place of residence		41-50	12.9%
Rural area	17.2%	51 and over	6.9%
City up to 50,000 residents	12.4%	**Education**	
City up to 100,000 residents	7.1%	Basic education /vocational education and lower secondary education	4.3%
City up to 250,000 residents	10.2%	In college	17.7%
City above 250,000 residents	53.1%	Secondary education	26.0%
		Higher education	52.0%

3.2. Car drivers' knowledge about engine oil

The question about the frequency of oil change was the first issue that respondents were asked to answer. They were to select the best answer from the given alternatives. The results are presented in Fig. 1.

Changing the oil after driving 10,001-15,000 km was indicated by the majority (48%) of participants. Changing the oil after a year regardless of the number of kilometres travelled or during a mandatory inspection according to the service book was the most suitable answer for 17% of respondents. 14% of respondents reported changing oil in their car after driving 15,001-20,000 km, 6% after driving more than 20,000 km and 7% after driving less than 10,000 km. Approximately 8% of those surveyed selected one of the three options: With different frequency – I do not pay attention to mandatory vehicle check periods (5.3%), I do not change it at all (I only top it up) (1.1%), I do not know (1.4%). These participants ignore manufacturer's recommendations as to oil change time and therefore risk damage to their cars as well as to the environment. Used oil is characterised by an increased content of harmful components which then interfere with the recovery process and have toxic effect on ecosystems if released to the environment.

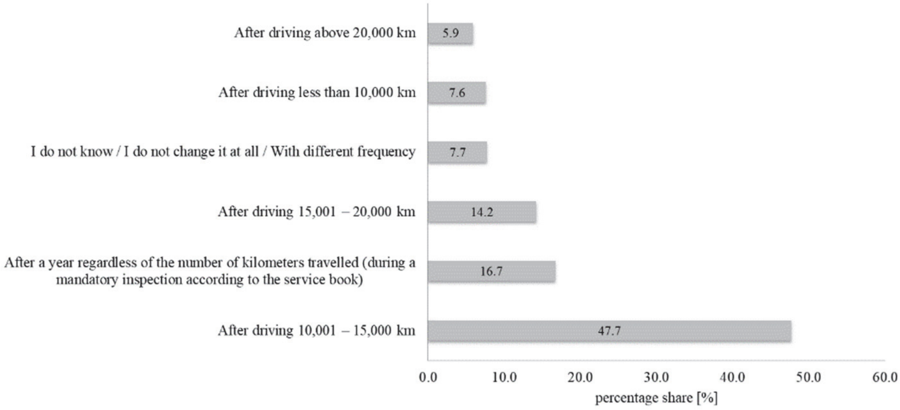


Fig. 1. Frequency of oil change among respondents

The second question was related to the factors influencing the decision of car drivers about the time of engine oil change (Fig. 2).

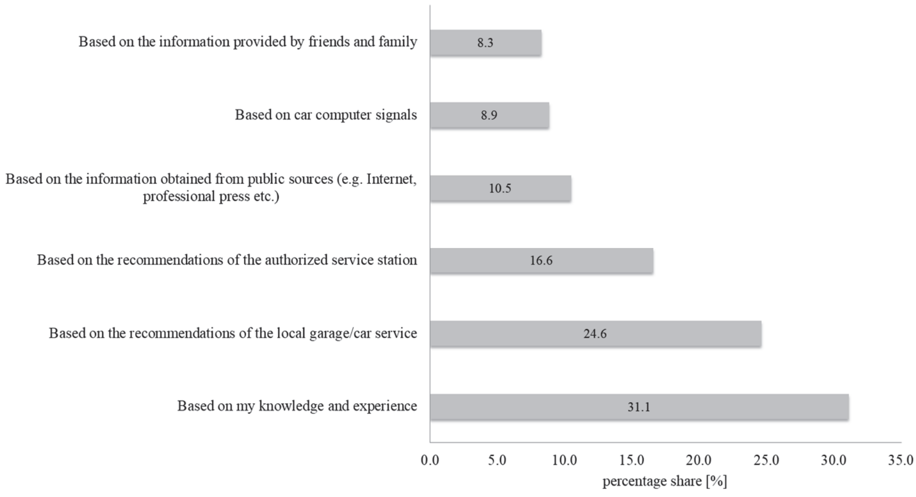
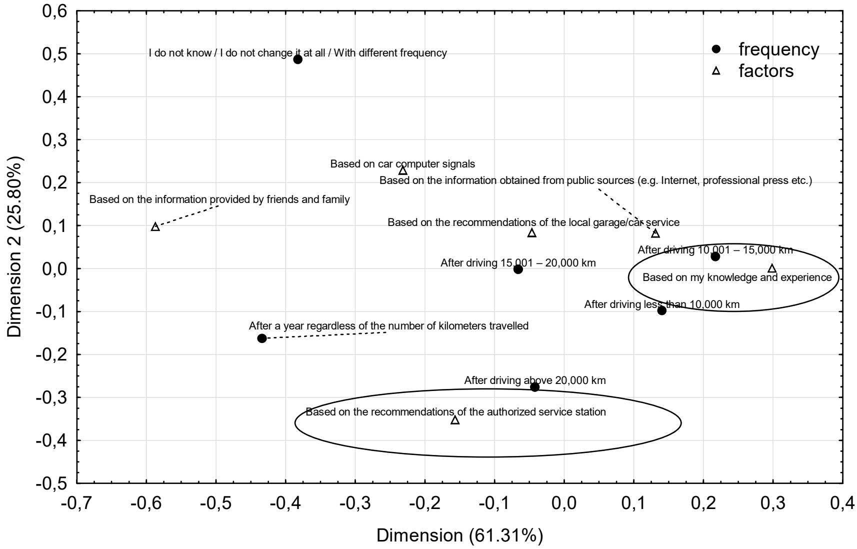


Fig. 2. Factor determining the oil change interval

Almost 1/3 of the respondents (31%) determined the oil change time based on their knowledge and experience. For 42% of respondents, the recommendations of the local garage/car service (25%) or recommendations of the authorized service station (17%) were the most significant factors. Based on the assumption that service stations staff are knowledgeable about engine oils, one can expect that the chosen oil change time will be optimal. Almost 9% of respondents decided on the time of engine oil change based on car computer signals. Approximately 18% of those surveyed believed that the most adequate factor to indicate the suitable time is the information provided by friends and family (8%) or obtained from public sources (e.g. Internet, professional press etc.) (10%). The obtained results confirm the complexity of the studied subject. There is no one dominant criterion which drivers take into consideration when deciding on the optimal use time for their cars (Smith & Sutton, 2011).

Figure 3 depicts the map of frequency of oil change among respondents and factors determining the oil change interval.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,26	0,07	61,31	61,31	97,65
2	0,17	0,03	25,80	87,10	41,09

Fig. 3. Correspondence analysis map of the frequency of oil change among respondents plus factors determining the oil change interval and Inertia decomposition

Dimension 1 is represented by the horizontal axis, dimension 2 – by the vertical axis. A two-dimensional space (two axes) explains more than 87% of total inertia. Although distances between categories of frequency of change and factors determining decision are not mathematically set, their degree of "clustering" or nearness of points on the map with regards to their angle from the origin and directs in the same quadrant can be used as outlines to interpret relationships between column and row variables. We can see that respondents changed the oil in their cars after driving 10,001-15,000 km, determining the oil change time based on their knowledge and experience. Therefore, in the case of those who change the engine oil after 10,001-15,000 km, the decision was governed by their knowledge and experience more often than in the case of the rest of respondents. Moreover, dimension 2 indicates that a relatively higher number of drivers who change the oil after driving more than 20,000 km follow the recommendations of authorised service stations. Car manufacturers systematically prolong the oil change intervals by using synthetic oils which, fortified with additives, guarantee long and reliable engine operation. As per the obtained results, prolongation of the oil use periods is noticeable mainly in the case of the group of respondents who follow the recommendations of authorised service stations. Among the people who decide based on their own knowledge, the oil change intervals are shorter. It can be due to incomplete knowledge and following recommendations which are no longer valid or can be caused by difficult conditions of oil use – e.g. short-distance city driving.

A vast majority of respondents (80%) have the oil changed in a garage/car service (67.5%) or in authorised service stations (12.9%) (Fig. 4), which may suggest that the oil will be managed properly and recycled. Changing the oil on one's own (only every fifth respondent changes oil at their own or their friend's garage) there is a significant risk of uncontrolled release of the oil to the environment.

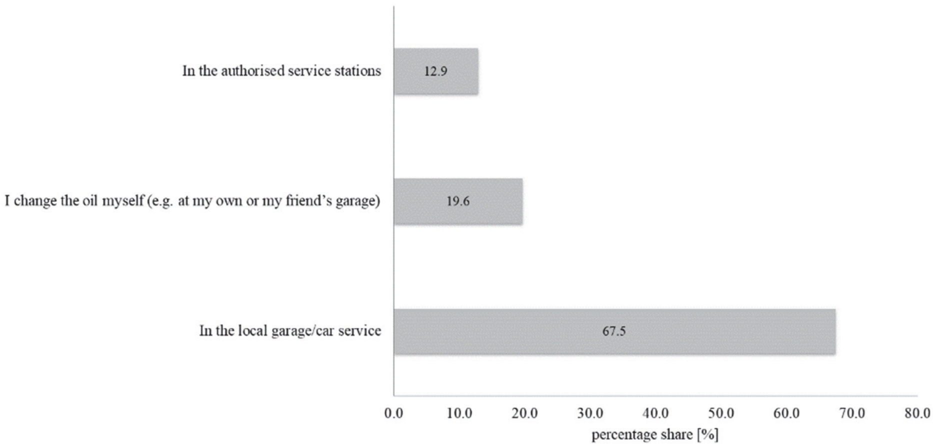
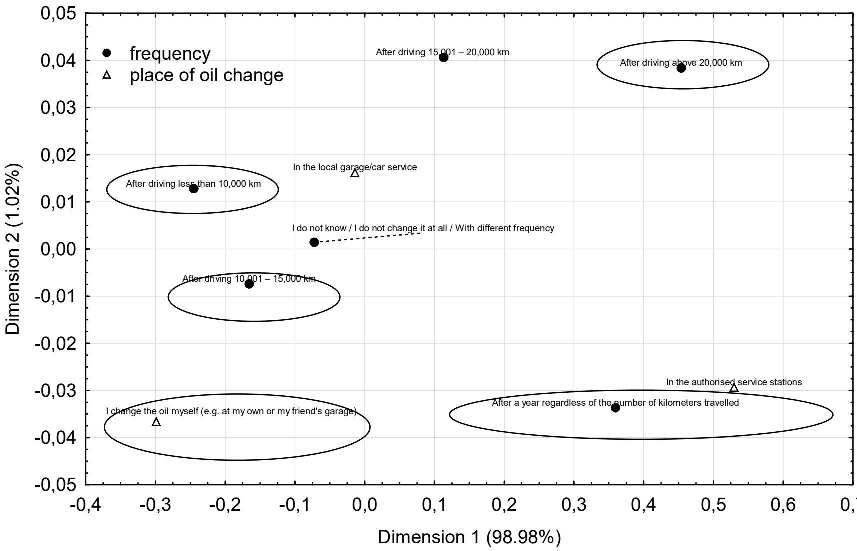


Fig. 4. Place of oil change

Figure 5 depicts the map of the frequency of oil change among respondents and the place of oil change.

The obtained two-dimensional space provides a summative explanation of 100% of total inertia. Changing the oil in authorised service stations has the highest contribution to total inertia. A relatively higher number of drivers who use the services of authorised service stations change the oil once year, regardless of the number of kilometres driven or after driving more than 20,000 km. The results of the correspondence analysis indicate that respondents who change the oil on their own (at their own or their friend's garage, etc.) most often change the oil after driving more than 15,000 km.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,23	0,05	98,98	98,98	77,74
2	0,02	0,00	1,02	100,00	0,80

Fig. 5. Correspondence analysis map of the frequency of oil change among respondents plus the place of oil change and Inertia decomposition

In the subject literature, there are no detailed reports of the influence of top-ups on the chemical and physica properties of engine oils and therefore this aspect was also included in the questionnaire. In their paper, Zając et al. focused on determining the influence of topping up the oil during car use on the change of concentration of chosen trace elements (Zając et al., 2018). They have demonstrated that topping up the oil by 10% of the capacity of the oil sump caused an increase in the concentration of the analysed elements from 0.4% to 7% (w/w), depending on the element and the studied oil.

According to the study, 57% of respondents declared topping up engine oil during use – 30% of them declared the amount of less than 0.5l of top-ups between oil changes 19% – 0.5-1l and 8% – more than 1l (Fig. 6). 43% of respondents do not top up the oil in intervals.

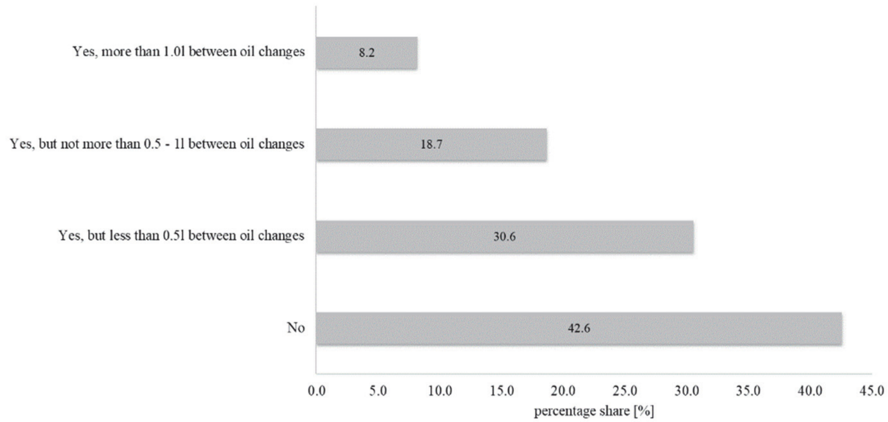
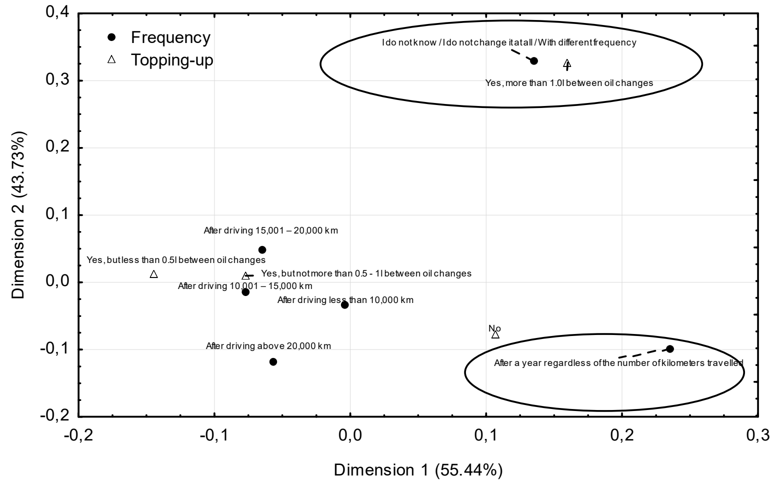


Fig. 6. Topping up engine oil

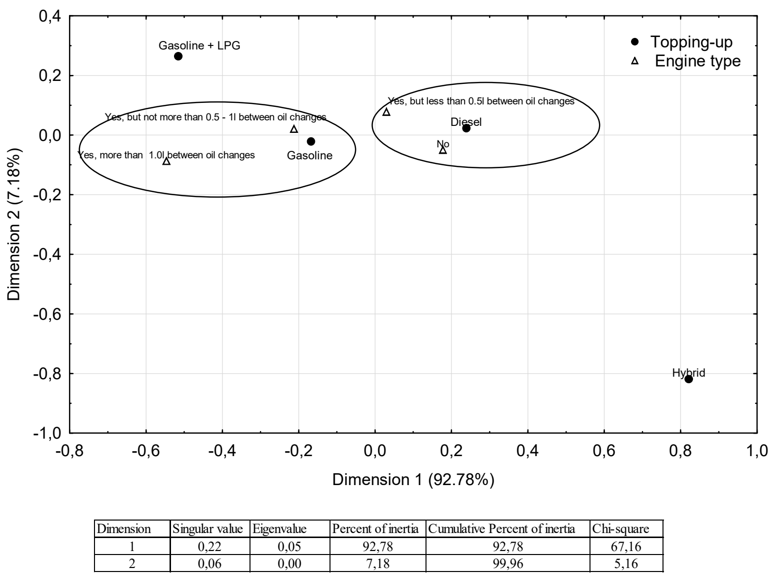
Applying correspondence analysis to the obtained results resulted in a two-dimensional space explaining more than 99% of total inertia (Fig. 7). Drivers who declared topping up the oil by more than 1l in intervals, stated more often than the others that they do not change the oil in their cars or change it with varied frequency, without keeping track of the mileage. A relatively higher number of drivers who do not top up the oil change it regularly once a year, regardless of the number of kilometres driven. Figure 8 shows that diesel car drivers either do not top up the oil or only top it up by less than 0.5l. Diesel engine cars are fitted with DPF systems which increase the content of fuel in engine oil and therefore the level of oil is correct, which does not imply that the oil is in good condition. Among petrol car users, more of them top up the oil by 0.5-1l and above 1l. The top-ups are due to oil loss caused by evaporation or leaks. The top-ups can result in keeping the oil in a good condition for a longer time (oil refreshment).

The next step of the presentation of the obtained results was to examine whether the frequency of oil change is related to the place of residence, level of education and age of car owners. On analysing Fig. 9, it can be noted that dimension 1 that explains nearly 74% of total inertia is the dominating one. Dimension 2 explains only 17.4%. On analysing the perceptual map, a significant division can be noted between the group of people from rural areas who change the oil after a relatively low number of kilometres driven (below 10,000 km).



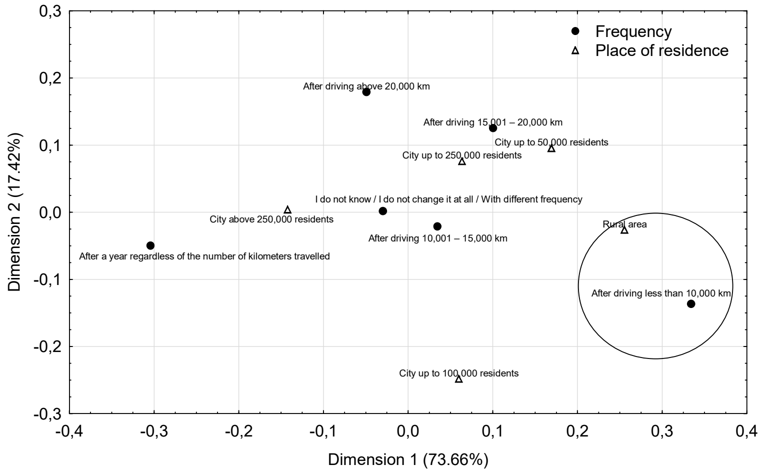
Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,12	0,01	55,44	55,44	20,77
2	0,11	0,01	43,73	99,17	16,38

Fig. 7. Correspondence analysis map of the frequency of oil change among respondents plus topping up the engine oil and Inertia decomposition



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,22	0,05	92,78	92,78	67,16
2	0,06	0,00	7,18	99,96	5,16

Fig. 8. Correspondence analysis map of engine type plus topping up the engine oil and Inertia decomposition

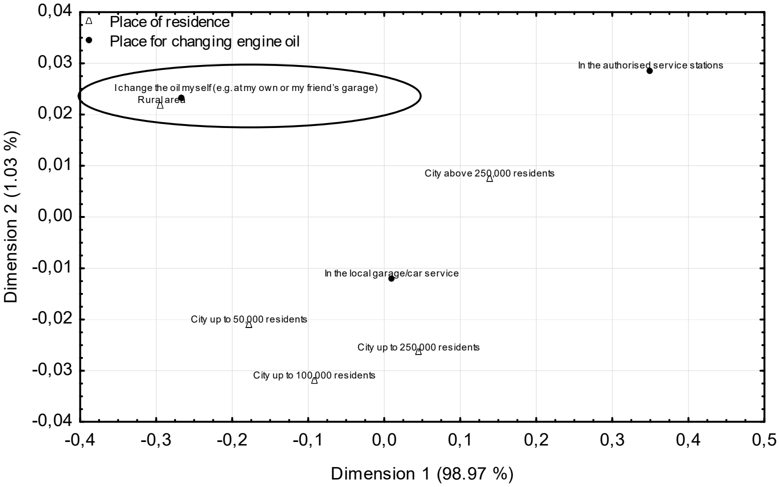


Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,16	0,03	73,63	73,63	37,90
2	0,08	0,01	17,42	91,05	8,96

Fig. 9. Correspondence analysis map of the frequency of oil change among respondents plus place of residence and Inertia decomposition

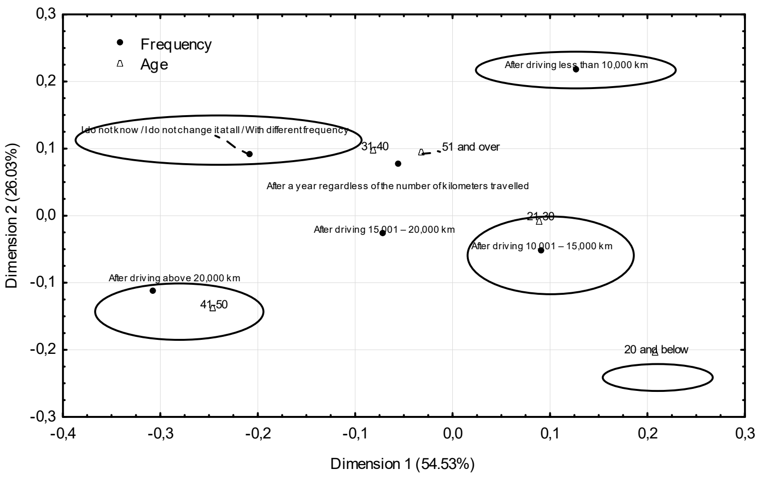
Additional analysis of correlations between the place of residence and place of oil change (Fig. 10) shows that the respondents from rural areas change the oil on their own more often than respondents from those living in agglomerations. It may be due to the fact that in rural areas there are fewer car services and therefore drivers who have basic knowledge about oil change decide to do it in their own garages. However, the place of use (rural area) seems not to be a sufficient reason for changing oil after driving less than 10,000 km. It seems to be rather due to the fact that drivers decide based on their own knowledge which may not be sufficient to determine the time of oil change.

On analysing Fig. 11, it can be noted that, in total, the two-dimensional space explains only above 80% (the least of all the analysed variables). Dimension 1 explains more than 54% of inertia, while dimension 2 – above 26% of total inertia. On analysing the perceptual map, a clear division into two groups can be noted: (1) young drivers (up to 30 years of age) more often than older drivers state that they change the oil after driving up to 15,000 km, (2) drivers between 41-50 years of age relatively more often change the oil after driving more than 20,000 km, do not change it at all or alternatively top up the oil or change it with varied frequency.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,17	0,03	98,97	98,97	42,96
2	0,02	0,00	1,03	100,00	0,45

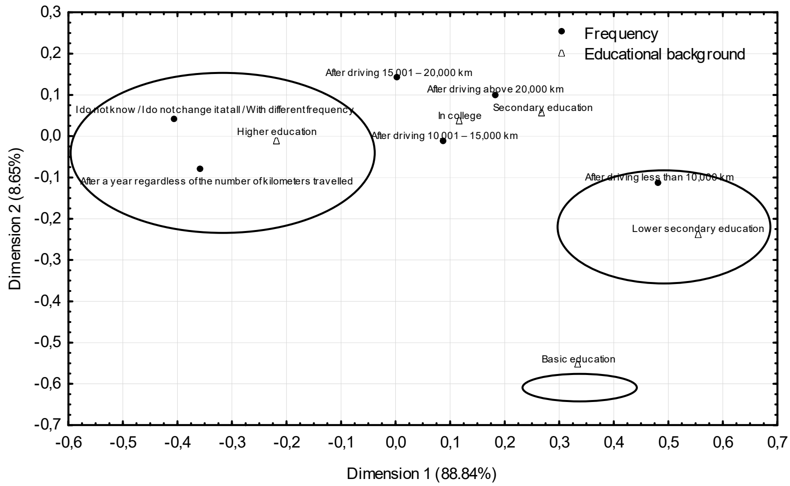
Fig. 10. Correspondence analysis map of place for engine oil change plus place of residence and Inertia decomposition



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,12	0,02	54,53	54,53	22,26
2	0,09	0,01	26,03	80,56	10,63

Fig. 11. Correspondence analysis map of the frequency of oil change among respondents plus their age and Inertia decomposition

The level of education is another variable for which a perceptual map was created. On analysing it, it can be noted that dimension 1, which explains nearly 90% of inertia, is significantly dominant, whereas dimension 2 explains only nearly 9% (Fig. 12). On analysing the mutual position of the marks representing the frequency of oil change and the level of education, it can be noted that two clusters have been formed: (1) drivers with basic and lower secondary education who relatively more often than those with higher education change the oil after driving not more than 10,000 km, (2) drivers with higher education who change the oil every year regardless of the number of kilometres driven (presumably due to convenience/lack of time) or do not change it at all, top up the oil or alternatively change the oil with varied frequency.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,24	0,06	88,84	88,84	83,36
2	0,07	0,01	8,65	97,49	8,12

Fig. 12. Correspondence analysis map of the frequency of oil change among respondents plus educational background and Inertia decomposition

The next step was to analyse whether the frequency of engine oil change is related to the car mileage, year of manufacture, engine type, engine capacity and the percentage share of the car use in urban /extra-urban driving conditions. Table 2 combines respondents' answers related to the specification of cars they drive and the character of use (urban / extra-urban driving).

Table 2. Detailed specifications of the cars used by the survey respondents (n=1446)

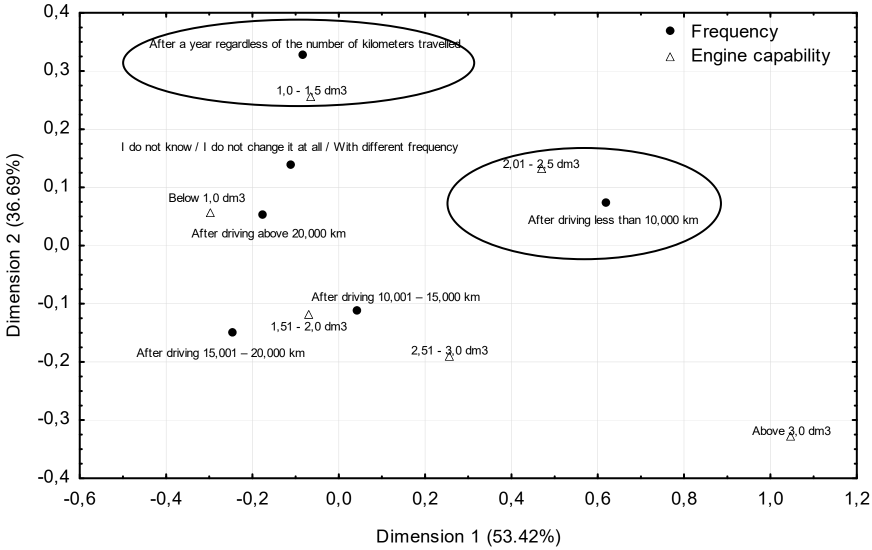
Car mileage [km]		Engine	
<50,000	8.8%	Diesel	55.7%
50,000-99,999	11.1%	Gasoline	42.2%
100,000-149,999	13.9%	Hybrid/Gasoline+LPG	0.3%/1.8%
150,000-199,999	18.1%	**Year of car manufacture**	
200,000-249,999	24.6%	<1994	1.0%
250,000-300,000	14.8%	1995-1999	8.7%
>300,000	8.7%	2000-2004	29.5%
The percentage share (0-100%) of the car use in city driving conditions		2005-2009	33.7%
0%-10%	0.7%	2010-2014	17.8%
11%-20%	1.4%	>2015	9.3%
21%-30%	4.4%	**Engine capacity**	
31%-40%	6.4%	Below 1.0 dm^3	1.8%
41%-50%	6.9%	1.00-1.50 dm^3	25.6%
51%-60%	9.5%	1.51-2.00 dm^3	59.6%
61%-70%	9.3%	2.01-2.50 dm^3	9.1%
71%-80%	18.5%	2.51-3.00 dm^3	2.5%
81%-90%	19.6%	Above 3.00 dm^3	1.4%
91%-100%	23.3%		

The sample had the following characteristics:

- over 50% of the cars covered an overall mileage of more than 200,000 km, with the range of 200,000-249,999 km (24.6%) being dominant,
- almost 20% of the cars covered a mileage lower than 100,000 km,
- the majority of the respondents (61.4%) declared above 70% share of the car use in city driving conditions,
- 55.7%% of respondents had cars with diesel engines, 42.2% of respondents had cars with gasoline engines,
- the year of manufacture of over 60% of cars was later than 2005, with the range of 2005-2009 (33.7%) being dominant,
- less than 10% of respondents drove cars older than 18 years old (year of manufacture earlier than 2000),
- over 85% of the car engines had the capacity below 2.00 dm^3, with the range of 1.51-2.00 (59.6%) being dominant.

The results of correspondence analysis for the variables from Table 2 are displayed in Figures 13-17.

On analysing Figure 13, it can be noted that dimension 1 is strongly influenced by the group of drivers who have cars with engine capacity of 2.0-2.5 dm^3 (inertia = 0.47), whereas dimension 2 is dominated by the group of drivers who drive cars with engine capacity of 1.0-1.5 dm^3 (inertia = 0.58). Relative inertia for the two engine capacities is above 0.5 (0.51). Based on the conducted study, a relation was confirmed between drivers who have cars with engine capacity of 1.0-1.5 dm^3 and changing oil once a year regardless of the number of kilometres driven, as well as between drivers who have cars with engine capacity of 2.0-2.5 dm^3 and changing the engine oil after driving less than 10,000 km.

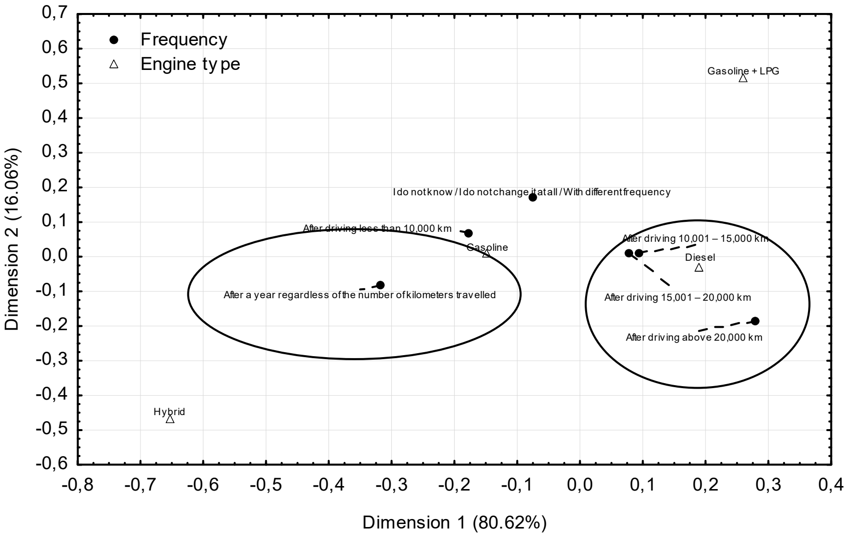


Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,21	0,04	53,42	53,42	61,34
2	0,17	0,03	36,69	90,10	42,12

Fig. 13. Correspondence analysis map of the frequency of oil change among respondents plus engine capability and Inertia decomposition

The obtained two-dimensional space for the type of engine variable indicates that dimension 1 explains more than 80% of inertia and is strongly influenced by both gasoline engines (inertia 0.41) and diesel engines (inertia 0.51) (Fig. 14). The significance of hybrid engines is very low (mass amounts to 0.0027 relative to e.g. 0.5574 for diesel engines). It is due to, inter alia, a low number of respondents driving cars with hybrid engines. Nevertheless, this category is well represented in the dimension. Respondents who drive cars with hybrid engines change the oil once a year regardless of the number of kilometres driven or after driving 15,001-20,000 km.

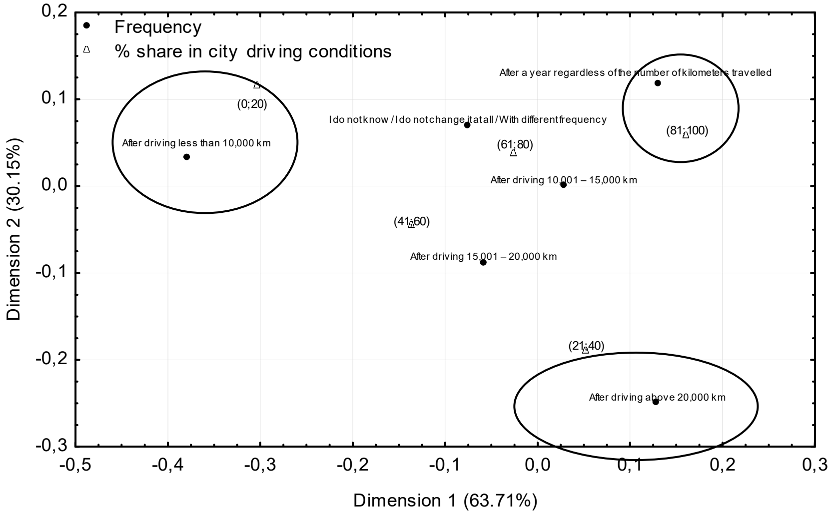
Drivers who drive cars with gasoline engines change the oil more frequently (after driving less than 10,000 km or after a year regardless of the number of kilometres driven) than those who drive cars with diesel engines (after driving more than 10,001 km).



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,17	0,03	80,62	80,62	42,57
2	0,08	0,01	16,06	96,69	8,48

Fig. 14. Correspondence analysis map of the frequency of oil change among respondents plus engine type and Inertia decomposition

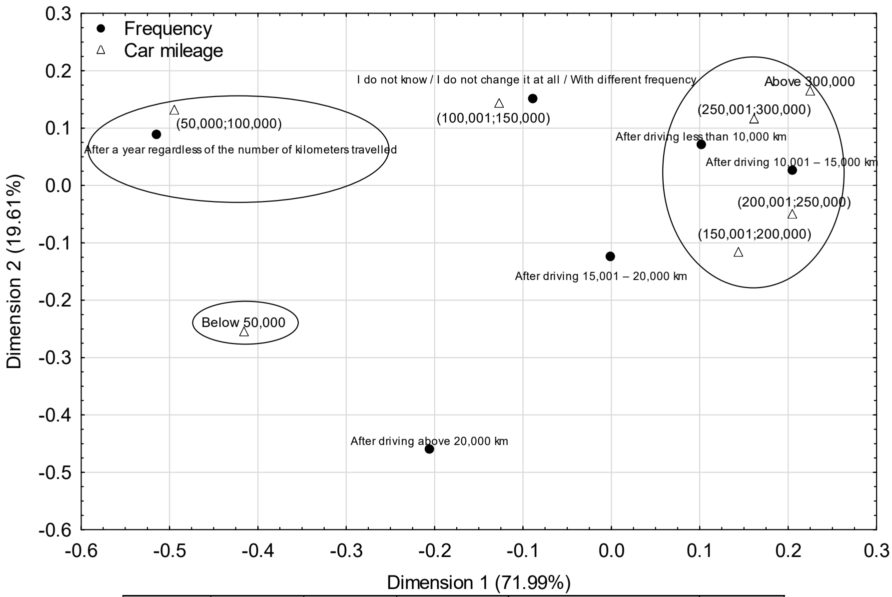
On analysing Figure 15 it can be noted that dimension 1 is strongly influenced by the category of drivers who declare the percentage share of city driving between 80%-100% (inertia = 0.43) and between 0%-20% (inertia = 0.32), whereas dimension 2 is strongly dominated by car drivers who declare the percentage share of city driving between 20-40% of total mileage within oil change intervals (inertia = 0.67). Applying correspondence analysis to establish the relation between the share percentage of city driving and frequency of oil change indicates several correlations: More drivers who use their cars in city driving conditions (around 80%) change the oil after driving less than 10,000 km. Among drivers who declare the share of city driving on the level of 21-40% there is relatively more drivers who change the oil after driving more than 20,000 km. The group of drivers who declare the percentage share of city driving on the level of 61-80% (the lowest relative inertia = 0.05) is underrepresented in the dimension. Its location may be misleading when assigning to an appropriate group representing the frequency of engine oil change.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,13	0,02	63,71	63,71	23,14
2	0,09	0,01	30,15	93,86	10,95

Fig. 15. Correspondence analysis map of the frequency of oil change among respondents plus % share in city driving conditions and Inertia decomposition

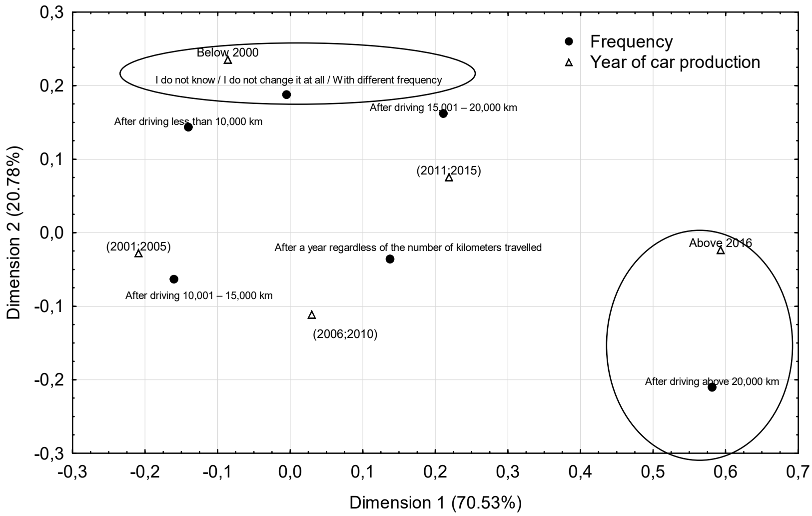
Figure 16 shows that the obtained two-dimensional space explains more than 91% of total inertia. It can be noticed that the group of respondents that changed the oil in their cars once a year regardless of the number of kilometres driven clusters with the group of respondents whose cars covered a mileage of up to 100,000 km (for dimension 1 the two categories are the strongest – “below 50,000” and “50,000-100,000”, inertia = 0.26 and 0.40 respectively). Therefore, drivers who have cars with mileage of up to 100,000 km change the oil once a year regardless of the number of kilometres driven more frequently than the rest. Moreover, dimension 1 indicated that relatively more drivers who change the engine oil after driving not more than 15,000 km drive cars with total mileage not exceeding 150,000 km.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0.26	0.07	71.99	71.99	98.64
2	0.14	0.02	19.61	91.61	26.87

Fig. 16. Correspondence analysis map of the frequency of oil change among respondents plus car mileage and Inertia decomposition

On analysing Figure 17, it can be noted that dimension 1 explains over 70% of inertia and is strongly influenced by the category of drivers who drive cars not older than 3 years (year of manufacture later than 2015 – inertia = 0.44), whereas dimension 2 is dominated by drivers who drive cars older than 18 years (year of manufacture later than 2000 – inertia = 0.60). Applying correspondence analysis to establish the relation between the year of manufacture and the frequency of oil change indicates several correlations: Drivers who drive older cars (year of manufacture earlier than 2000) more often declare that they do not change the oil but only top it up, or else change the oil with varied frequency without a set schedule. Among drivers who drive new cars (year of manufacture earlier than 2015) the dominant frequency of oil change is after driving more than 20,000 km.



Dimension	Singular value	Eigenvalue	Percent of inertia	Cumulative Percent of inertia	Chi-square
1	0,21	0,04	70,53	70,53	62,75
2	0,11	0,01	20,78	91,31	18,49

Fig. 17. Correspondence analysis map of the frequency of oil change among respondents plus year of car production and Inertia decomposition

New cars are usually serviced in authorised service stations, which entails conducting an interim review and changing the oil regularly. Therefore, the oil change intervals are in line with the recommendations of the service stations, as displayed in Fig. 3. However, old cars (older than 18 years) users take care of their vehicles to a lesser extent, hence the less frequent oil change. Changing the oil is an additional expense, which drivers may perceive as unnecessary if their cars are of low value. For this reason, some respondents in the group do not change the oil at all or do it occasionally.

4. Conclusions

To sum up the study results presented above, it should be emphasised that applying the correspondence analysis tool allowed to prove numerous correlations between the frequency of oil change and particular variables, which can be helpful in the assessment of the behaviour of car users as to oil change. The most important correlations are the following:

1) More than 90% of respondents change the oil regularly (the highest percentage of respondents (48%) change the oil after driving 10,001-15,000 km). However, more than 7% of respondents ignore the significance of regular oil change thus risking damage to their cars and to the environment.

2) Almost 1/3 of the respondents (31%) determined the oil change interval based on their knowledge and experience. For 42% of respondents, the recommendations of a local garage/car service (25%) or recommendations of an authorized service station (17%) were the most important factors.
3) A relatively higher number of drivers who change the engine oil after driving 10,000-15,000 km choose the oil change time following their own knowledge or experience.
4) A relatively higher number of drivers who change the oil after driving more than 20,000 km follow the recommendation of authorised service stations.
5) 57% of respondents declared topping up the oil during use. Drivers who declare topping up the oil by more than 1l in intervals, more often than others indicated not changing the engine oil or changing it with varied frequency, without following any schedule.
6) Young drivers (up to 30 years of age) more often than older drivers declare changing the oil after driving up to 15,000 km. Drivers between 41-50 years of age relatively more often drive more than 20,000 km without changing the oil, or do not change the oil at all, or alternatively top up the oil or change the oil with varied frequency.
7) Drivers with basic or lower secondary education relatively more often than those with higher education change the oil after driving no more than 10,000 km. Drivers with higher education who change the oil once year regardless of the number of kilometres driven or do not change the oil at all tend to top up the oil or change it with varied frequency.
8) Owners of cars with 1.0-1.5 dm^3 engine capacity more often than others change the oil after a year, regardless of the number of kilometres driven. Owners of cars with 2.0-2.5 dm^3 engine capacity more often than others change the oil after driving less than 10,000 km.
9) Drivers who use their car mostly in city-driving conditions (around 80% of time) more often change the oil after driving less than 10,000 km. Among drivers who drive in city-driving conditions for 21%-40% of time, there are relatively more drivers who change the oil after driving more than 20,000 km.
10) Drivers who drive cars with a mileage of up to 100,000 km more often than others change the oil once a year regardless of the number of kilometres driven.
11) Drivers who drive older cars (year of manufacture earlier than 2000) more often than others state that they do not change the oil but only top it up, or alternatively change the oil with varied frequency without a set schedule. Among drivers who drive new cars (year of manufacture later than 2015) the dominant frequency of oil change is after driving 20,000 km.

For obvious reasons related to car use, oil should be changed at a mileage recommended by the car manufacturer. Every oil change is an additional expense for a car owner and therefore one would expect that drivers tend to delay the oil change rather than doing it earlier than recommended. However, the results of the study show that drivers tend to change the engine oil earlier than it is recommended by the car manufacturer. The results of the study also proved that there is no one decisive factor which determines the oil change time. Around 40% of drivers follow the recommendations of authorised service stations or car services when scheduling oil change. Also, around 40% follow either their own experience or recommendations of friends and family. The first group tends towards a maximisation of the number of kilometres driven (more than 20,000 km), whereas according to the second group, oil should be changed earlier (after driving 10,000-15,000 km). Unfortunately, not having conducted a study that includes sampling of used engine oils (a study of physico-chemical properties), it is difficult to determine which choice is the right one.

A positive side of the study is that a vast majority of drivers (80%) have oil changed in car services and authorised service stations and only 20% change it on their own. Such a pattern guarantees that a significant part of waste oil is properly collected and managed. Changing oil on one's own increases the risk of it being released to the environment or managed in a manner contrary to the existing rules.

A bigger education campaign connected with scientific research seems to be necessary in order to establish clear guidelines for optimal oil change intervals. The most important recommendations for a potential educational campaign should include:

1) authorised laboratory test results confirming the actual oil lifetime, expressed as a number of kilometres travelled (about 10% of the respondents ignore the importance of regular oil change)
2) hierarchy of variables affecting the extension / reduction of the lifetime of lubricating oils (e.g. urban driving, extra-urban driving).
3) benefits of changing oil in specialist authorised service centres / car workshops / maintenance institutions.
4) making drivers aware of how the used/waste oil is being recycled.
5) making drivers aware of the serious consequences of the release of used/waste oil into the environment.

Changing oil too early (unconsciously) leads to detrimental effects, including a negative impact on the environment. It is estimated that approximately 45 million tonnes of waste oil are generated each year, which means that about 126,000 tonnes of such waste are collected on a daily basis. So, with each passing day, a conscious use of engine oils becomes a measurable benefit, translating into a reduced amount of used/waste engine oil, of which only a small part is being fully recycled, whereas about 60% of it still poses a potential threat to the environment.

Just like with any research, especially those empirical in nature, the analysis presented in this article has its limitations. These are mainly conditioned by the method of the sample selection and the sample size. Above all, the population was limited to engine oil buying people in Poland. Another potential limitation of the research affecting the correctness of the results obtained are slight deviations in the composition of the studied group from the typical driver population. There is a minor overrepresentation of drivers from cities and drivers with higher education.

Initial steps have been taken to expand the scope of the study to other countries. Scientific centres in the UK, Switzerland, Spain, Slovakia, the Netherlands, Germany, Czech Republic and Belgium are currently conducting studies.

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Abstract

Used engine oils are considered hazardous waste. They contain many potentially harmful substances. The amount of engine oil in passenger cars is not big however, due to the number of cars in use, the overall amount used in the EU amounts to several million tons. Despite the fact that engine oil change interval is generally set by the car manufacturer, usually it is rather determined by the knowledge and attitude of drivers. Timely oil change, apart from having an obvious influence on the engine wear process, also has a big impact on the environment. Therefore, studying the motives and factors which govern the oil change is crucial for optimizing the period of engine oil exploitation. The paper presents the results of a questionnaire on the frequency of oil change, the factors influencing the oil change time, the place of oil change and oil top ups. Moreover, thorough research has been conducted to connect the frequency of oil change with additional factors influencing the level of degradation of the engine oil. More than 1400 drivers participated in the study. The results were analysed with the use of correspondence analysis. The results presented in the paper show various correlations between the frequency of oil change and particular variables thus allowing for an assessment of drivers' behaviour with regard to oil change. A need has been identified to implement a bigger education campaign concerning the oil change time and conduct research in order to establish guidelines for optimal oil change intervals.

Keywords:
waste lubricant oil (WLO), oil degradation, environmental impact and damage,
engine oil change schedule, public awareness, public attitudes, questionnaire,
predicting car drivers' behaviour

Empiryczna analiza czynników wpływających na częstotliwość wymiany oleju silnikowego w aspekcie środowiskowym

Streszczenie

Oleje silnikowe zalicza się do odpadów niebezpiecznych. Zawierają wiele substancji niebezpiecznych (np. wielopierścieniowe związki oraz węglowodory aromatyczne). W samochodach osobowych ilość oleju silnikowego nie jest duża, niemniej jednak liczba poruszających się pojazdów powoduje, że ilość oleju w obiegu ogólnym w EU jest rzędu kilku milionów ton. Mimo że termin wymiany oleju jest zazwyczaj określany przez producenta pojazdu to w rzeczywistości jest on pochodną wiedzy i zachowania kierowców. Terminowa wymiana oleju silnikowego w pojazdach oprócz oczywistego wpływu na zużycie silnika ma również duży wpływ na środowisko. Zbyt wczesna wymiana zwiększa ilość olejów odpadowych i powoduje większe zużycie zasobów naturalnych, natomiast zbyt późna wymiana oleju powoduje nadmierną akumulację szkodliwych związków w oleju. Stąd poznanie motywów i czynników, jakimi kierują się kierowcy przy wymianie oleju stanowi istotny element w optymalizacji długości eksploatacji oleju silnikowego. W pracy przedstawiono wyniki badań ankietowych w zakresie częstotliwości wymiany oleju, czynników wpływających na termin wymiany, miejsce wymiany oleju oraz stosowania dolewek oleju. Ponadto podjęto próbę powiązania częstotliwości wymiany oleju z dodatkowymi czynnikami (m.in. przebieg samochodu, eksploatacja miasto-trasa, pojemność silnika) wpływającymi na stopień degradacji oleju. Zebrano opinie ponad 1,400 użytkowników pojazdów. Do analizy wyników zastosowano opisową i eksploracyjną technikę analizy danych, jaką jest analiza korespondencji. Przedstawione w pracy wyniki pozwoliły wykazać istnienie wielu zależności pomiędzy częstotliwością wymiany oleju silnikowego a poszczególnymi zmiennymi, które pozwoliły ocenić zachowania użytkowników samochodów w zakresie wymiany olejów. Zdiagnozowano również konieczność przeprowadzenia szerokiej kampanii edukacyjnej w zakresie terminów wymiany olejów oraz badań naukowych, mających na celu opracowanie wytycznych związanych z optymalnym czasem eksploatacji oleju silnikowego.

Słowa kluczowe:
zużyty olej silnikowy, degradacja oleju, wpływ na środowisko i szkody,
harmonogram wymiany oleju silnikowego, świadomość społeczna, postawy społeczne,
ankieta, przewidywanie zachowania kierowców samochodów