Faculty of Operation and Economics of Transport and Communications
University of Žilina
Žilina, Slovakia

TRANSPORT AND COMMUNICATIONS

Scientific journal

tac.uniza.sk

II/2021 Volume IX ISSN 1339-5130

TRANSPORT AND COMMUNICATIONS

Scientific journal intended to combine theory and practice in the field transport and communications and thus advancement of transport and communications sciences

DOI: 10.26552/tac.J.2021.2
ISSN 1339-5130

Table of contents

 DOI: 10.26552/tac.C.2021.2.1

The Analysis of Vehicle Use Intensity in a Transportation Company

Paweł Droździel[1]

[1]Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland

Abstract Intensity of use is one of the most important parameters of vehicle operation. It is expressed as the number of kilometres travelled by a car within a specified period of time (day, month, or year). The intensity of use affects vehicle life, the costs and the profits from transportation services, drivers' working time, and other parameters of car operation. For that reason, analysis of data associated with the intensity of vehicle use may be instrumental in the evaluation of a given transport system. The paper presents and discusses the results of statistical analyses of data related to the intensity of use of delivery trucks in the Poczta Polska company in Lublin.

Keywords transportation company, vehicle usage, statistical analysis

JEL L91, L87, R41

1. Introduction

There are numerous indicators used to evaluate and compare the transport system of a transport company. These include profit from transport service, the weight of transported cargo, personnel costs, fuel, lubricating oil, repairs, etc. [3,4,5]. However, the intensity of vehicle use remains one of the most important parameters.

It is measured through the number of kilometres travelled by the vehicle over a specific time period (day, month or year). Many other factors and indices depend on the intensity of use: the period of use of a given vehicle, the costs and the profits obtained from the transportation service, driver's working time, as well as other parameters of vehicle operation [1,6,7,8,9].

Therefore, it seems that a thorough analysis of the data related to the intensity of vehicle use is important and helpful in the process of evaluating a given transport system. The paper presents and discusses the results of statistical analysis of the data obtained during the study related to the intensity of use of delivery vehicles of the Poczta Polska (Polish Post Office) in Lublin.

2. Characteristics of the vehicle fleet used in the transportation company

The author had the access to the data concerning 179 vehicles that were used in one year in Poczta Polska in Lublin. The studied fleet consisted of vehicles of many makes and types. They performed various transport tasks resulting from the operation and role of the post office. Based on the information obtained from the carrier, the vehicles were divided into three groups with different load capacities.

The group I included passenger vehicles with small load capacity (e.g. Fiat Seicento). The nature of their work involved driving between letterboxes and delivering mail in the city of Lublin and its nearest vicinity. This group comprised 47 vehicles. Group II consisted of delivery vans with an average load capacity (e.g. Lublin III). These vehicles transported mail between post offices in Lublin and the former Lublin Province. This group consisted of 85 cars. Vehicles with large load capacity (e.g. Iveco Stralis) were classified in group III. They were used to transport parcels between logistic centres of Poczta Polska on routes outside the territory of the former Lublin Province. This group included 47 vehicles.

3. Results of statistical analyses of the intensity of vehicle use

The data on the intensity of vehicle use acquired from Poczta Polska in Lublin were statistically analysed using the Statistica PL software package. The results for the whole fleet of the studied vehicles as well as for the groups of vehicles are presented in Table 1.

Table 1. Position and scatter parameters of the annual intensity of vehicle use in the studied transport company

Group	Mean value	Median	Min. value	Max. value	Standard deviation	Standard error
	$\bar{l}$	me			σ_l	δ_l
	[km/year]	[km/year]	[km/year]	[km/year]	[km/year]	[km/year]
Group I	14437	12144	1248	46511	8432	1230
Group II	34762	35315	67	97707	17716	1922
Group III	83597	87771	3515	164244	48239	7036
Groups I, II and III	42248	30316	67	164244	38082	2846

Figure 1 and Figure 2 shows the statistical histograms for the annual intensity of vehicle use.

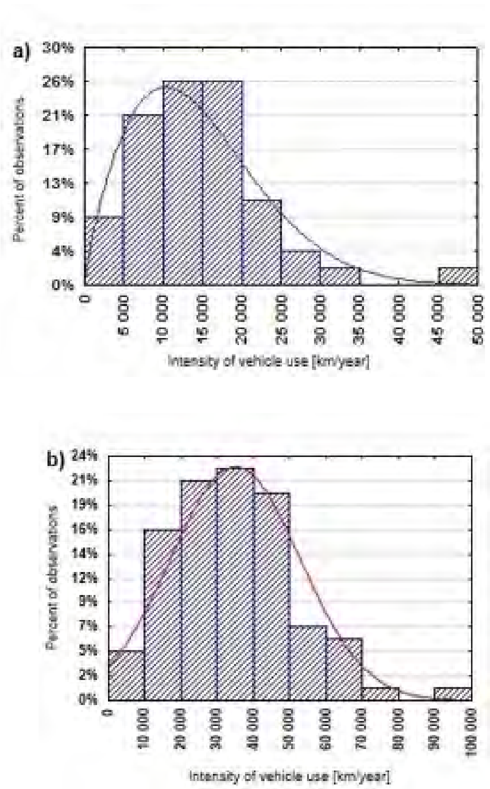


Figure 1. Statistical distribution of annual intensity of vehicle use; (a) group I density function fit to empirical data by Weibull distribution (significance level p<0.01) with scale parameter: 16225.25 and shape parameter: 1.796, (b) group II density function fit to empirical data by normal distribution (significance level p<0.01) with position parameter: 34761.98 and scale parameter: 17716.66.

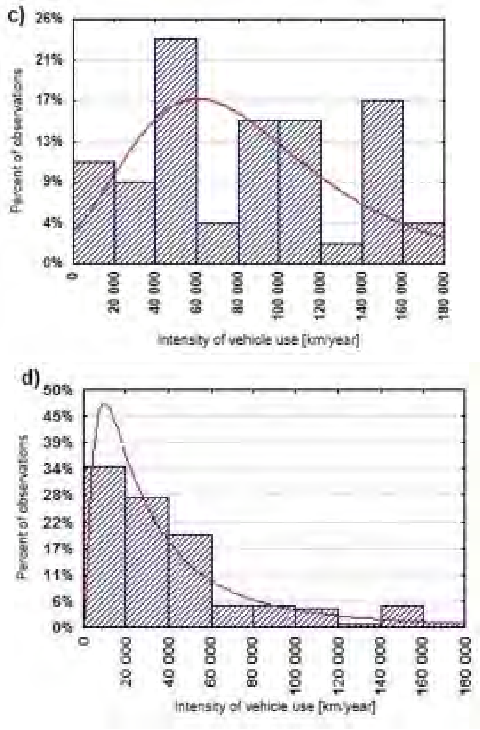


Figure 2. Statistical distribution of annual intensity of vehicle use; (c) group III density function fit to empirical data by extreme value distribution (significance level p < 0.01) with position parameter: 59936.11 and scale parameter: 42740.60, (d) all vehicles density function fit to empirical data by lognormal distribution (significance level p<0.01) with scale parameter:10.24 and shape parameter: 1.04

While discussing the distributions from Figures 1 and 2, it should be stated that the annual intensity of vehicle uses in group I does not exceed 10,000 km/year in 30.2% of the observed cases. The mileage up to 20,000 km/year occurs in almost 82%. For group II, mileages up to 20,000 km/year occur in 21%, and up to 40,000 km/year in 64.2% of cases. For group III, mileage up to 20,000 km/year constitutes only 11% of the cases. In this group, 43.6% of observations the annual intensity does not exceed 60 thousand km/year. For group III, the share of the annual mileage exceeding 140,000 km/year is significant (21.1%).

When analysing the results of the calculation of statistical parameters presented in Table 1, attention should be paid to the differences occurring between the values of the average annual intensity of use in individual groups of vehicles. To check whether the observed differences are statistically significant, an analysis of variance was performed.

Its first step is to check whether the empirical data can be approximated by a normal distribution. As it can be seen from Figures 1 and 2, the histograms of the annual intensity of vehicle use for groups I and III cannot be fitted by a normal distribution. This was also confirmed by the analysis performed using the chi-square $\chi 2$ test. Additionally, the occurrence of variance heterogeneity in individual vehicle groups was found. The Bartlett's B test [2] was applied (because of a non-uniform number of objects in the analysed groups). The value of the test statistic was B=134.48 at the significance level of p=0.001.

Failure to meet the assumptions about the normality of the distribution of the analysed variable and the heterogeneity of the variance made it impossible to apply the method of classical analysis of variance to the observed annual values of vehicle use intensity. Therefore, in further calculations, the non-parametric method of analysis of variance using the Kruskal-Wallis K-W test [2] was applied. The calculations showed that the value of the statistic is K-W=80.145 with a significance level of p=0.001. This result indicates that there is a significant difference between the mean value of the annual intensity of vehicle use in particular groups.

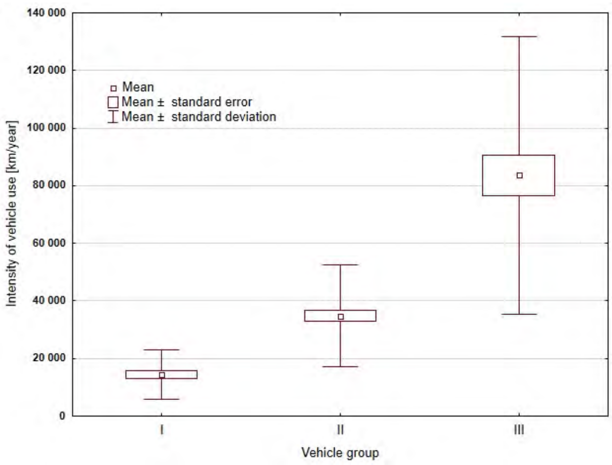


Figure 3. Categorized box plot for the independent factor, i.e. vehicle group and the dependent variable, i.e. annual vehicle use intensity

Figure 3 presents a categorized box plot for the annual intensity of use depending on the distinguished group of vehicles. The observed occurrence of differences for the average value of the annual intensity of use between the groups of vehicles results from the nature and scope of the transport work performed.

In further analyses, it was checked whether the month (as a grouping factor) has a significant effect on the average value of the monthly intensity of vehicle use in individual groups. The calculations carried out using the chi-square $\chi 2$ test showed the conformity of the distributions of the mean monthly intensity of vehicle use in individual groups with a normal distribution. Homogeneity of variance was also checked using the Bartlett B test [2]. The obtained results are presented in Table 2.

Table 2. Bartlett's test results for homogeneity of variance for vehicle use intensity for the grouping factor – month of operation

Group	Statistic **B**	*p* value
I	6.80	0.814
II	5.12	0.925
II	4.56	0.950

The results pertaining to the homogeneity of variance for monthly usage intensity in each vehicle group presented in Table 2 indicated that the classical analysis of variance method could be applied. The results of the calculations performed using the Fisher F test are presented in Table 3.

Table 3. Results of the analysis of variance for the factor grouping – month of operation

Group	Statistic **F**	*p* value
I	1.567	0.104
II	1.392	0.170
II	1.698	0.071

The obtained results presented in Table 3 allow stating that the month of operation (as a grouping factor) does not significantly affect the value of the observed average monthly intensity of vehicle use. This is confirmed by the categorized box plots presented in Figure 4 for the monthly intensity of use in each group of vehicles.

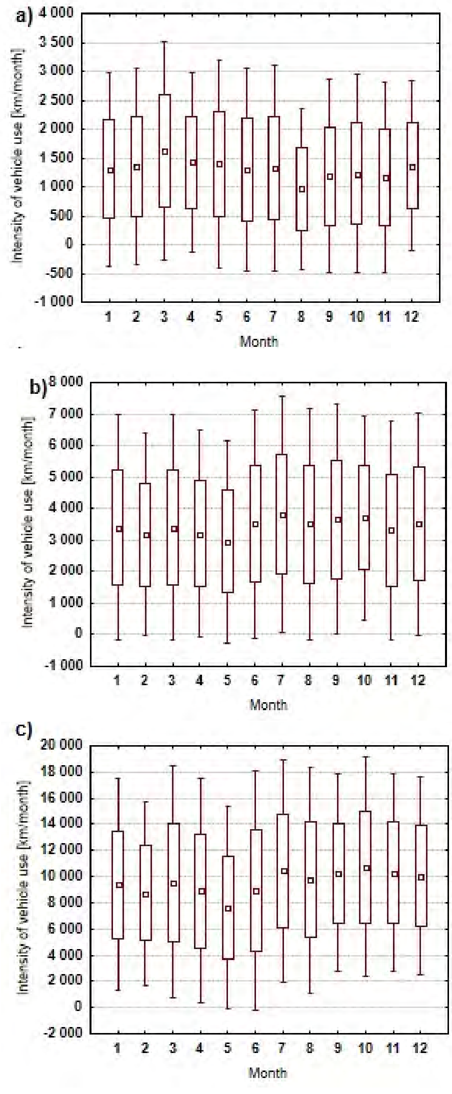


Figure 4. Categorized box plot for the independent factor, i.e. month and the dependent variable, i.e. monthly vehicle use intensity; (a) group I, (b) group II, group III

4. Conclusions

The obtained results of statistical analyses performed and discussed in the article for the data related to the intensity of use of vehicles of the Poczta Polska in Lublin allow drawing the following conclusions:

1. The division of the vehicle population into three groups based on the size of the cargo space is correct. It is indicated by significant differences between particular groups for average values of annual and monthly intensity of vehicle use.
2. In group II, the values of the average annual intensity of vehicle use were almost 2.5 times higher than those observed in group I. A similar proportion occurred also for the intensity of vehicle use of group III, relative to group II.
3. Month of operation has no significant effect on the observed values of the average monthly intensity of vehicle use in particular groups.

The obtained results indicate that the vehicles perform transportation according to a well-defined travel plan. This allows concluding that decision-making related to transportation routing in Poczta Polska is a properly executed process.

Finally, it should be added that the statistical analyses were conducted for the information related to the process of vehicle operation for one year. Therefore, it cannot be determined unequivocally whether there is the repeatability of the results for the observed values of vehicle utilization intensity in other years. For this purpose, similar calculations should be performed for the data from at least several years of vehicle operation in each transportation company. The authors hope to carry out further research on this topic in the future.

REFERENCES

[1] Droździel P., Krzywonos L.: A model of the economic effectiveness of the truck transportation services, Transport Problems, vol. 5 issue 4, Gliwice, Wyd. Politechniki Śląskiej 2010.

[2] Dobosz M.: Wspomagana komputerowo statystyczna analiza wyników badań. Wydawnictwo, Warszawa, EXIT 2004.

[3] Hebda M.: Eksploatacja samochodów, Radom, Wyd. ITE – PIB 2005.

[4] Mendyk E.: Ekonomika transportu, Poznań, Wyd. WSL. 2009.

[5] Rydzykowski W., Wojewódzka-Król K.: Transport, Warszawa, PWN 2009.

[6] Smalko Z.: Podstawy eksploatacji technicznej pojazdów, Warszawa, Wyd. Politechniki Warszawskiej 1998.

[7] Woropay M., Landowski B., Jaskulski Z.: Wybrane problemy eksploatacji i zarządzania systemami technicznymi. Bydgoszcz, Wyd. Uczelniane Akademii Techniczno-Rolniczej w Bydgoszczy 2004.

[8] Madlenak, R., Madlenakova, L., Stefunko, J.: The variant approach to the optimization of the postal transportation network in the conditions of the Slovak republic. Transport and Telecommunication Journal, 16(3), 2015, pp. 237-245. doi:10.1515/ttj-2015-0022

[9] Madlenak, R., Madlenakova, L.: Comparison of Regional Postal Transportation Networks in Zilina Region. In Transport Means 2015, Pts I and II, 2015 (pp. 277-280).

DOI: 10.26552/tac.C.2021.2.2

Research on Wear of Liners in Diesel Engines During Start-ups

Paweł Drożdziel[1], Piotr Ignaciuk[1], Paweł Kordos[1]

[1]Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland

Abstract This paper presents the methodology and results of tests of the start-up wear of the cylinder liner in vehicle diesel engines. The conducted tests were aimed at determining the starting wear of the cylinder liner, as well as the influence of the starting temperature and other factors on the observed wear value.

Keywords diesel engine, cylinder testing, starting wear testing

JEL L62, L90, C15

1. Introduction

The start-up of a vehicle internal combustion engine is a transitional process accompanied by the occurrence of many negative tribological processes. At the beginning of the start-up, due to insufficient amount of engine oil (inertia of the engine lubrication system) and too low relative velocity of the moving surfaces of its tribological pairs, the occurrence of the so-called boundary friction is noted [5,6,10].

As the engine oil flows to the engine tribological nodes, the boundary friction turns into mixed friction. Only when a sufficient relative velocity and amount of lubricating oil are achieved between the moving surfaces of kinematic pairs (usually occurring after the engine start-up), favourable conditions for the occurrence of liquid friction appear [7,10,11]. The described transition from boundary friction (in extreme cases from dry friction) to mixed friction with a low percentage of liquid friction causes that adhesive and abrasive wear can be observed in the tribological nodes of the internal combustion engine during start-up, in addition to corrosive wear in the PRC system [6,8].

As a result, the start-up wear is characterized by a higher wear rate than that occurring during the normal operation of the internal combustion engine The start-up wear of the cylinder liner bearing surface during a single start of an internal combustion engine constitutes from 8% to 75% of its total operational wear. The values of the equivalent start-up wear range from a few to several hundred or even several thousand kilometres of vehicle mileage or several (up to 10) hours of operation on an engine test bench [6,11].

2. Research objects and the methodology of research

The research was conducted on 359M and 4CT90 diesel engines. The basic technical parameters of these engines are presented in Table 1.

Table 1. Selected technical parameters of the 359M and 4CT90 engines

Specification	Engine parameter value	
	359M	4CT90
Number of cylinders [pcs.]	6	4
Cylinder diameter [mm]	110	90
Stroke [mm]	120	95
Displacement [dm^3]	6.842	2.417
Compression ratio	17	20.6
Rated power [kW]	110	66
Rotational speed of rated power [rpm]	2800	4100
Maximum torque [Nm]	440	195
Rotational speed at the max torque [rpm]	1800-2100	2500
Idle speed [rpm]	500-600	800±20
Maximum rotational speed [rpm]	3100	4100
Compression pressure [MPa]	2.4	3.0
Oil pressure in the lubrication system [MPa]	0.2-0.	0.38-0.

The PRC system of the 4CT90 engine uses a piston with two sealing rings and one wiper ring. In the PRC system of the 359M engine, the piston is sealed in the cylinder liner by three O-rings and includes one wiper ring.

The wear assessment of cylinder liner bearing surfaces during the start-up of the tested engines was carried out on a special engine testbed at the Department of Internal Combustion Engines, Lublin University of Technology. Electronic measurement and control systems used on the stand allowed for continuous control of the temperature of the coolant and engine oil. A heater and a water cooler in the engine oil pan, as well as a heater in the engine coolant heat exchanger and a water pump operating when the engine is stopped, were installed to stabilize the above-mentioned temperatures. Fluctuations in coolant and lubricating oil temperatures during the series of start-ups did not exceed ± 2.5°C.

For the tested diesel engines, a series of start-ups was performed with the parameters shown in Table 2. After starting, the engine idled for several dozen seconds. After the engine was stopped, it was brought back to the assumed start-up temperature.

Table 2. Parameters of the various start-up series of the 359M and 4CT90 engines

Series 359 engine	Number of engine start-ups	Water and lubricating oil temperature [K]	Series 4CT90 engine	Number of engine start-ups	Water and lubricating oil temperature [K]
Series no. 1	500	283 (10°C)	Series no. 1	1000	291 (18°C)
Series no. 2	700	293 (20°C)	Series no. 2	1000	308 (35°C)
Series no. 3	1000	333 (60°C)	Series no. 3	1000	328 (55°C)
			Series no. 4	1000	248 (75°C)

3. Methodology of testing the wear of cylinder liners

In the conducted tests, the increase in their internal diameter was assumed as a measure of the wear of cylinder liners in the 359M and 4CT90 engines. In order to determine this increase, the surface of individual cylinder liners was cut with a diamond blade, creating the so-called "artificial bases". A special UPOI6 device was used for this purpose. The applied wear assessment method is characterized by an accuracy of 1 μm.

In order to avoid complete disassembly of the engines, the "artificial bases" were cut only after removing the head. This was done in accordance with the Industry Standard BN-79/1374-04, perpendicular to the direction of friction in measurement planes (levels) at different heights of the cylinder liner measured from the block surface and for four directions - parallel (A-A) to the crankshaft axis, perpendicular (B-B) to this axis and at an angle of 45°C to the crankshaft axis (C-C, D-D), as shown in Figure 1.

The first three measurement planes for the 4CT90 engine and the four measurement levels for the 359M engine correspond to the centers of their piston ring positions at TDC. The greater number of measurement levels of the 4CT90 engine resulted from better technological possibilities of cutting the "artificial base". The "artificial bases" cut in each measurement plane were marked sequentially from 1 to 8 clockwise, starting from the base on the A-A direction closest to the front of the engine.

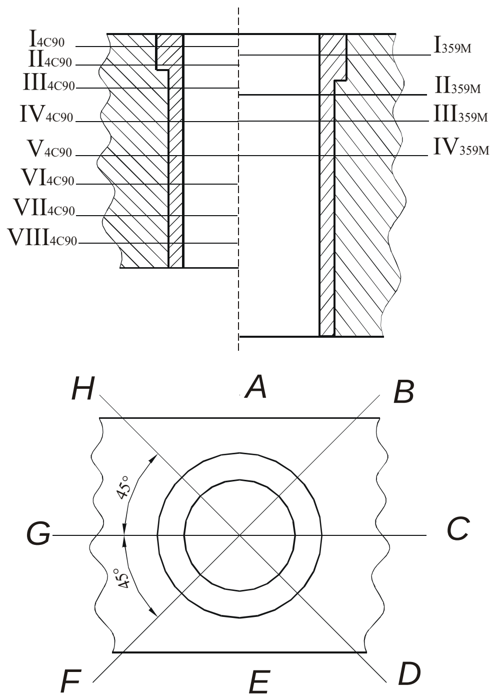


Figure 1. Scheme of cutting artificial bases on the surface of cylinder liners of the tested engines; height (level) of notching the bases along the 4CT90: – 23 mm, III_{4CT90} – 30 mm, IV_{4CT90} – 40 mm, V_{4CT90} – 50 mm, VI_{4CT90} – 60 mm, VII_{4CT90} – 70 mm and the 359M engine: I_{359M} – 23 mm, II_{359M} – 36.5 mm, III_{359} – 55.5 mm.

The first three measurement planes for the 4CT90 engine and the four measurement levels for the 359M engine correspond to the centers of their piston ring positions at TDC. The greater number of measurement levels of the 4CT90 engine resulted from better technological possibilities of cutting the "artificial base". The "artificial bases" cut in each measurement plane were marked sequentially from 1 to 8 clockwise, starting from the base on the A-A direction closest to the front of the engine.

After each series of start-ups, the engine head was removed and the changes in the length of the "artificial base" were read, which made it possible to assess the wear of the cylinder liner surface (increase in its internal diameter). The value of the single radial wear of the liner surface is calculated from the following formula, see Figure 2:

$$z_{ri} = \frac{1}{8} \cdot \left(\frac{1}{r} - \frac{1}{R} \right) \cdot \left(l_p^2 - l_k^2 \right), \quad (1)$$

where:

z_{ri}– value of the ***i***-th radial wear of the cylinder liner [μm],
r – knife radius 9.4 [mm],
R – radius of curvature of the tested surface 45 or 55 [mm],
l_p – initial cut length [μm],
l_k – end length of the cut, [μm].

The value of wear (increase) of the inner diameter of the cylinder liner is:

$$d_i = z_{rxj} + z_{rxk} \ , \qquad (2)$$

where:

$\boldsymbol{d_i}$ – value of the ***i***-th cylinder liner wear (increase in the inner diameter) [m],µ

z_{rxj}– value of radial wear at the level $\boldsymbol{x}$ = I, II, ..., VII and direction j = 1,..,4µm],

z_{rxk}– value of radial wear at the level $\boldsymbol{x}$ and direction $\boldsymbol{k = j + 4}$ [µm].

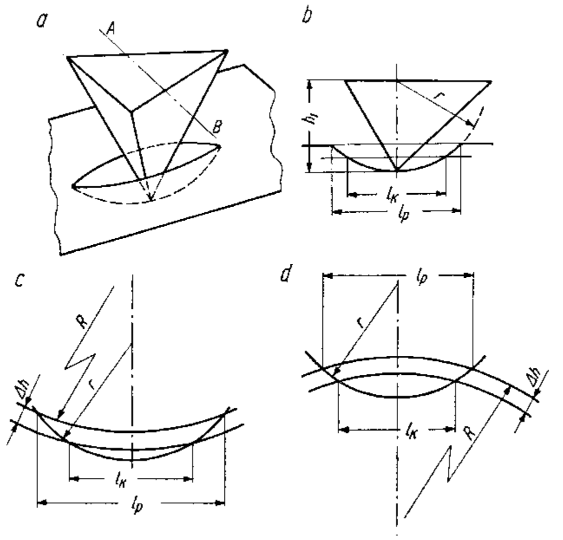


Figure 2. Scheme for calculating the depth of cuts; **R** – radius of curvature of the tested surface, **r** – knife radius, $\mathbf{l_p}$ – initial cut length, $\mathbf{l_k}$ – final cut length, $\mathbf{h_1}$ – knife height, **Δh** – linear wear value

.

4. Research results

After reading the changes in the length of the "artificial base", the wear of the cylinder liner was calculated using the formulas (1) – (2). Then, a preliminary statistical analysis of the obtained results was carried out using the STATISTICA software package, and the elimination of the "gross error" results was performed by calculating the lower limit of the confidence interval:

$$d_d = \bar{d} - t_{1-\alpha_{pi0}/2} \cdot \sigma_d \cdot \sqrt{\frac{n}{n-2}} \ , \qquad (3)$$

and the upper end of the confidence interval:

$$d_g = \bar{d} + t_{1-\alpha_{pi0}/2} \cdot \sigma_d \cdot \sqrt{\frac{n}{n-2}} \ , \qquad (4)$$

where:

$\boldsymbol{d_d}$ –lower end of the confidence interval,

$\boldsymbol{d_g}$ – upper end of the confidence interval,

$\boldsymbol{t_{1-\alpha pi/2}}$ – quantile of Student's t-distribution with n-2 degrees of freedom.

The results from calculations of the confidence interval limits were obtained at the confidence level $\alpha_{pi/2}$=0.1 where $t_{1-\alpha pi/2}$ = 1.659 [1]. After taking into account and rejecting the questionable results from further analysis, the final selected parameters of the position and the spread of the start-up wear of the cylinder liners were calculated. Additionally, to compare the obtained values, the results of the cylinder liner wear of the 359M engine in series 1 and 2 were calculated per 1000 starts. The results of the statistical calculations are presented in Tables 3 and 4.

It should be emphasized that at a temperature of 75°C for the series of 4 starts of the 4C90 engine, no case of radial wear was found. The measurement method used in the research, based on "artificial bases", turned out to be too "sensitive".

Table 3. Parameters of the position and dispersion of the start-up wear of the cylinder liner after the rejection of questionable results for the 4CT90 engine [4]

	Series no. 1	Series no. 2	Series no. 3
Average value d [µm]	3.448	1.936	1.037
Variance Var [µm2]	2.138	2.232	1.178
Standard deviation s_d [µm]	1.462	1.494	1.085
Standard error d_d [µm]	0.151	0.143	0.102
Median m_e [µm]	2.357	2.149	0.0
Mode [µm]	2.243	0.0	0.0
Coefficient of variation v [%]	42.40	77.16	104.62
Max.value [µm]	6,675	4.658	2.736
Min. value [µm]	1.808	0.0	0.0

Table 4. Parameters of the position and dispersion of the start-up wear of the cylinder liner after the rejection of questionable results for the 359M engine [3]

Average value [µm]	Series no. 1	Series no. 2	Series no. 3
Variance Var [µm2]	7.645	6.397	6.419
Standard deviation s_d [µm]	0.207	4.318	3.915
Standard error d_d [µm]	0.445	2.078	1.978
Median m_e [µm]	0.051	0.222	0.214
Mode [µm]	7.598	5.656	6.099
Coefficient of variation v [%]	7.919	5.721	6.007
Max.value [µm]	máj.82	32.48	30.81
Min. value [µm]	9.406	11.116	sep.44
	6.728	2.762	2.231

4.1. Analysis of the variance of the obtained research results

In order to determine the influence of temperature and other grouping factors (cylinder, level, direction) on the wear of the engine cylinder liner during its start-up, an analysis of variance was performed using the STATISTICA software package. The first step in this analysis was to investigate whether the data came from a normally distributed population and whether all groups of results had the same variance.

The significance level was assumed to be α = 0.05. The chi-square test χ^2 was used for compliance testing with a normal distribution. For testing the homogeneity of variance, the Bartlett **B** [2] test was adopted (due to the unequal number of results in the analyzed groups).

The results of the analysis for the adopted temperature as the grouping factor for the tested engines are presented in Tables 5 and 6.

Table 5. Normal and uniformity test results for wear on the 4CT90; grouping factor – engine temperature

	Normality (N)		Homogeneity (J)		Decision	
	χ^2	value p	B	value p	N	J
Series I	41.13	0.000	12.73	0.001	no	no
Series II	59.86	0.000			no	
Series III	162.0	0.000			no	

Table 6. Normal and uniformity test results for wear on the 359M engine; grouping factor – temperature

	Normality (N)		Homogeneity (J)		Decision	
	χ^2	value p	B	value p	N	J
Series I	3.520	0.1720	141.0	0.00	yes	no
Series II	3.437	0.0637			yes	
Series III	8.082	0.0886			yes	

Based on the results presented in Tables 5 and 6, it is seen that the observed values of the wear of cylinder liner diameters for the 359M engine can be adjusted with the normal distribution, as opposed to the wear in the 4CT90 engine. This is confirmed by earlier studies [3,4]. In the statistical calculations for the analysed engines, it was also found that the normality tests were not met for the following grouping factors: cylinder, level and measuring direction.

Since the assumptions of the classic analysis of variance for the observed wear of the cylinder liner diameters of the 4CT90 and 359M engines during start-up were not fulfilled, a non-parametric method was used in the further analysis of variance using the Kruskal-Wallis **K-W** [2]. The results of this analysis are presented in Tables 7 and 8.

When analysing the results of the variance analysis presented in Table 7, it can be concluded that the temperature has a significant impact on the wear observed during the start-up of the 4CT90 engine.

Table 7. Kruskal-Wallis test results for 4CT90 engine wear (various grouping factors)

Grouping factor	K-W	p value	The influence of the factor on wear
Temperature	102.06	0.0000	**significant**
Cylinder	20.519	0.0001	**significant**
Cylinder in series I	14.751	0.0021	**significant**
Cylinder in series II	12.036	0.0073	**significant**
Cylinder in series II	5.249	0.1545	insignificant
Level	6.120	0.4098	insignificant
Level in series I	14.1418	0.0281	**significant**
Level in series II	3.017	0.8066	insignificant
Level in series III	7,912	0.2446	insignificant
Direction	1.800	0.6148	Insignificant
Direction in series I	2.6954	0.4410	Insignificant
Direction in series II	2.5255	0.4707	Insignificant
Direction in series III	0.7878	0.8524	Insignificant

During the start-up, the influence of another grouping factor, i.e. the cylinder, on the wear values of the cylinder liner is additionally observed. This is probably due to the lower lubrication of the last cylinder liner. Figures 3, 4 and 5 show categorized frame charts the value of cylinder liner wear for two grouping factors (temperature and cylinder for start-ups at 18°C and 35°C) of the 4CT90 engine.

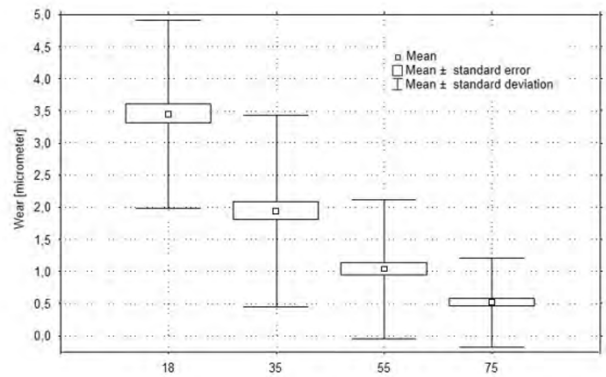


Figure 3. Categorized box plot for the temperature grouping factor and the dependent variable – wear on the cylinder liner diameter of the 4CT90 engine during its start-ups

Transport and Communications, 2021; Vol. II. DOI: 10.26552/tac.C.2021.2.2
ISSN: 1339-5130

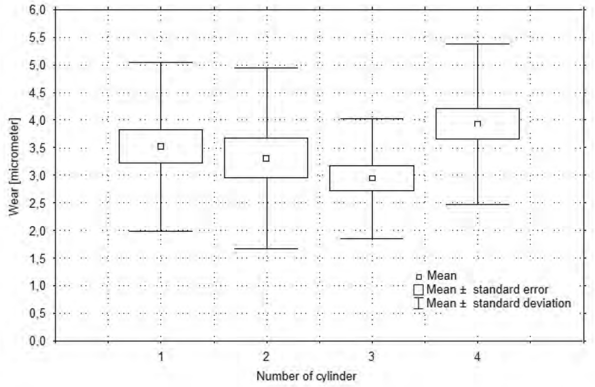


Figure 4. Categorized box plot for the cylinder grouping factor and dependent variable – wear on the cylinder liner diameter of the 4CT90 engine during its start-ups in series I

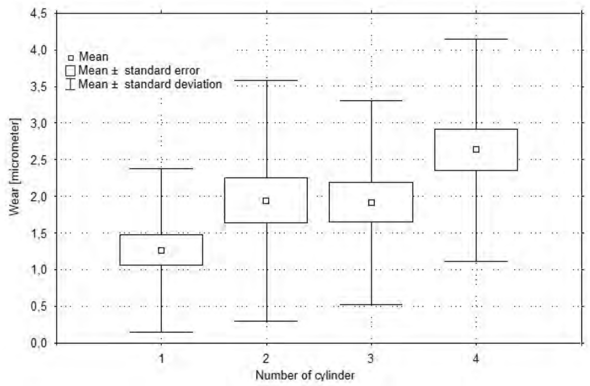


Figure 5. Categorized box plot for the cylinder grouping factor and dependent variable – cylinder liner wear on the cylinder liner diameter of the 4CT90 engine during its start-ups in series II

Table 8. Kruskal-Wallis test results for 359M engine wear (various grouping factors)

Grouping factor	K-W	p value	The influence of the factor on wear
Temperature	22.297	0.000	**significant**
Cylinder	6.467	0.2633	insignificant
Cylinder in series I	2.683	0.7487	insignificant
Cylinder in series II	14.040	0.0154	**significant**
Cylinder in series III	5.889	0.3376	insignificant
Level	2.753	0.4308	insignificant
Level in series I	0.775	0.8553	insignificant
Level in series II	1.110	0.7746	insignificant
Level in series III	1.017	0.7970	insignificant
Direction	1.984	0.5756	insignificant
Direction in series I	2.059	0.5602	insignificant
Direction in series II	2.045	0.5630	insignificant
Direction in series III	5.045	0.1685	insignificant

When analysing the results of the variance analysis presented in Table 8, it can be concluded that the temperature has a significant impact on the wear observed during the start-up of the 359M engine. Figure 6 shows the categorized box plot of the cylinder liner wear value for the grouping factor, i.e. the 359M engine start-up temperature.

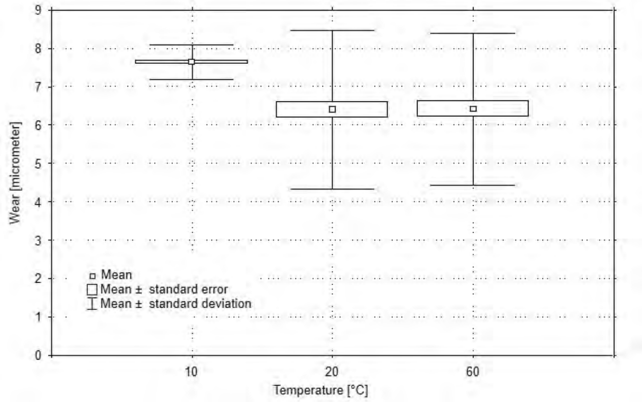


Figure 6. Categorized box plot for the temperature grouping factor and the dependent variable – wear on the cylinder liner diameter of the 359M engine during its start-ups

5. Conclusions

Based on the performed tests and the conducted statistical analysis of the obtained results from the cylinder liner wear assessment in 4CT90 and 359M diesel engines, it can be concluded that:

- The start-up wear of the cylinder liner bearing surface, measured by the increase in its internal diameter, depends significantly on the value of the engine start-up temperature. This is due to the increase in the influence of negative tribological processes on the wear intensity of the finishing coats as the temperature drops.
- The start-up wear value also depends on the type of injection. The use of indirect injection in a split combustion chamber (4CT90 engine) limits the variability of dynamic loads occurring in the PRC system. This improves the lubrication conditions in its tribological pairs and reduces the start-up wear.
- The value of the starting wear of cylinder liners of the tested engines does not depend on the direction and level of assessment. This observation is quite interesting because, according to other researchers, the wear value along the running surface of the cylinder liner during operation depends on the position in relation to the surface of the engine block (the TDC of the top ring).
- The occurrence of a significant field of scattering of the observed values of cylinder liner wear during engine start-up results from the complex friction process in the PRC system, and the accuracy of the "artificial base" method.

REFERENCES

[1] Bobrowski D.: Probabilistyka w zastosowaniach technicznych. WNT. Warszawa, 1986.

[2] Dobosz M.: Wspomagana komputerowo statystyczna analiza wyników badań. EXIT. Warszawa, 2001.

[3] Droździel P.: Изнашивание цилиндровых втулок в период пуска двигателя внутренного. Трение и износ. Том 22, № 6. Ноябрь – декабрь, 2001, s. 664-670.

[4] Droździel P., Ignaciuk P.: Zużycie tulei cylindrowych podczas rozruchu spalinowego silnika 4C90 o zapłonie samoczynnym. Zagadnienia Eksploatacji Maszyn, z. 4 (136), vol. 38. Polska Akademia Nauk, Komitet Budowy Maszyn, Radom, 2003.

[5] Holmes K.: Solid Materials. Engine Tribology. Tribology Series 26. Elsevier, 1993.

[6] Koliński K, Pszczółkowski J.: Zużycie cylindrów silnika AD4.236 w warunkach rozruchu. Eksploatacja silników spalinowych. Zeszyt nr 6. Problemy rozruchu silników spalinowych. Komisja Motoryzacji i Energetyki Rolnictwa PAN O/Lublin, Politechnika Szczecińska. Szczecin, 2002.

[7] Lawrowski Z.: Tribologia – Tarcie, zużywanie i smarowanie. PWN. Warszawa, 1993.

[8] Lewicki J.: Opory tarcia i zużycie silników z zapłonem samoczynnym przy rozruchu w niskich temperaturach. Prace Naukowe Politechniki Szczecińskiej. Nr 353. Szczecin, 1988.

[9] Smith M. F.: Understanding diesel engine lubrication at low temperature. SAE Paper 902177, 1990.

[10] Taylor C. M.: Lubrication regimes and the internal combustion engine. Engine Tribology. Tribology Series 26. Elsevier, 1993. [5]

[11] Włodarski J. K.: Tłokowe silniki spalinowe – procesy tribologiczne. WKiŁ. Warszawa, 1982.

Identification of Refund of Excise Duty on Motor Oils for International Road Freight Transport

Miloš Poliak[1], Iwona Ewa Tomaszewska[1], Marek Jaskiewicz[2], Natalia A. Zhuravleva[3], Natalia Lachmetkina[4], Ekaterina Salamakhina[1]

[1] University Of Zilina, Univerzitná 1, 010 26, Žilina, Slovakia
[2] Kielce University of Technology, Al. Tysiaclecia Pamstwa Polskiego7, 25-314 Kielce, Poland
[3] State Transport University St. Petersburg Polytechnic University, Polytechnicheskaya 29, Russia
[4] Russian University of Transport, Moscow, Russia

Abstract In this article, the authors focus on the issue of refunding excise duty on motor oils within Europe . Some states have a refund in their legislation, most European countries do not, and this creates pressure from carriers to make decisions , where and how much it pays to refuel in your vehicles for international transportation . For this article, research was conducted in the field of research, analysis and comparison of conditions for creating a competitive environment within the countries of Europe. The article also wants to point out that the reimbursement is not subject to national transport, respectively. international transport and drawing by foreign carriers in countries where reimbursement is introduced are supported..

Keywords Refundation, Excise duty, Freight transport, Price

JEL H29, L91, R40

1. Introduction

Tax revenue from excise duty on mineral oils can be classified as one of the highest, which is credited to the state budget of the country. The amount of state budget revenue depends on the volume of fuel consumed. Income for a particular country is not dependent on the volume of fuel consumed in its territory, but on the volume of fuel used in that country. For this reason, individual EU countries, as the EU is a single customs territory, are based on two assumptions: if the price of fuels increases, the withdrawal to the state budget will increase; if the price of fuels increases, the demand for refuelling abroad will increase, where the price level is lower. EU legislation sets a minimum level of taxation of fuels in the EU through directives, but the maximum level of taxation is not adjusted. From the position of carriers is an effort to minimize the cost of ensuring the transport of the shipment. Of the variable costs, fuel costs represent the highest share. This is up to 30 percent of the total cost. This means that carriers are looking for the option of fuel price with the lowest price. In relation to excise duty, the term excise duty refund can be encountered in some EU countries. This is a procedure where, by Member States refund a part of the excise duty to a foreign carrier so as to motivate it to draw fuel on its territory. The state has the advantage of obtaining excise tax revenue at least at the minimum rate and the carrier refuelling at a lower price by Hautzinger (1984).

The disadvantage in this case is the state in which the carrier would, under other conditions, draw fuel, which loses all the revenue from the excise duty. The purpose of this paper is to identify the excise refund procedure in each country and to verify the hypothesis that excise refund affects tax revenues in other countries. The paper also proposes a solution for uniform arrangements for the refund of excise duty throughout the EU so as not to distort the EU single market. Some applications are simulated in the Slovak Republic.

2. Overview of conditions of excise tax on mineral oils.

Since 2010, the EU Member States are obliged to comply with the minimum level of taxation of excise duties on mineral oils under two legal standards. The first is Council Directive 2003/96 / EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity. The second piece of legislation is Council Directive 2004/74 / EC of 29 April 2004 amending Directive 2003/96 / EC as regards the possibility for certain Member States to apply provisional exemptions or reductions in respect of energy products and electricity taxation. The standard was adopted because of a transition period where countries did not have to immediately apply the minimum level of taxation. This was intended for States where the minimum rates laid down in Directive 2003/96 / EC would create serious economic and social difficulties and could have an adverse effect on nationals and national economies. Member

States such as Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovenia and the Slovak Republic could apply the transitional period. At present, no Member State can apply this transitional period and must comply with a minimum level of taxation for diesel excise duty of € 330/1 000 liters.

The mineral oil excise duty shall be based on the quantity of mineral oil expressed in liters at 15 ° C (l) or in kilograms (kg) or the amount of energy contained therein, expressed in gigajoules (GJ) Holguín et al. (2005).

Although the EU directive sets a minimum tax rate, individual states apply their own level of taxation in their territory by Fernández et al. (2003). Figure 1 shows a comparison of the variations in excise duty rates in individual EU countries and its year-on-year change between 2017 and 2018. The highest tax rates are applied in Sweden, the United Kingdom, Italy and France. The lowest tax rates are applied in Bulgaria, Estonia, Luxembourg and Poland. The level of excise duty in all EU countries is shown in Figure 1.

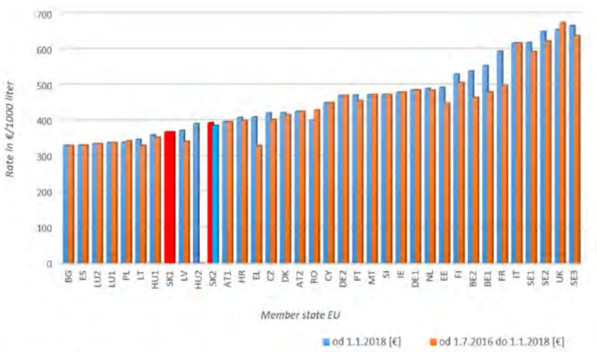


Figure 1. Change in excise duty rates on mineral oils in EU Member States

Table 1. Value added tax in EU Member States

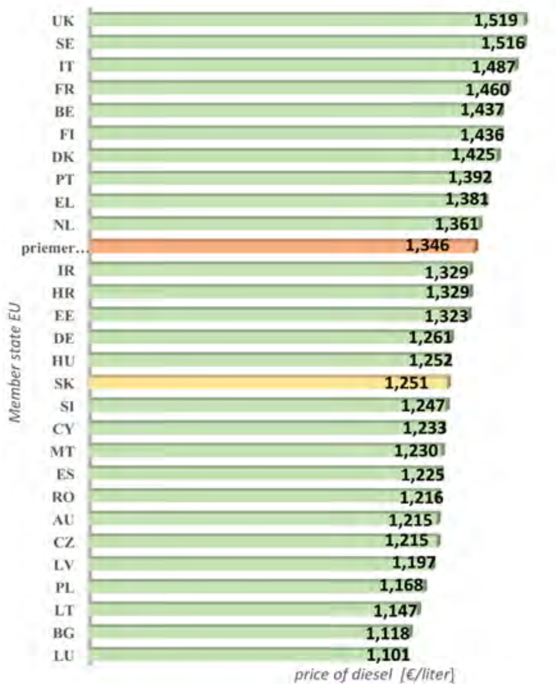
Country	VAT [%]	Country	VAT [%]
Luxemburg	17	**Lithuania**	21
Malta	18	**Latvia**	21
Germany	19	**Netherland**	21
Cypress	19	**Italy**	22
Romania	19	**Slovenia**	22
Bulgaria	20	**Greece**	23
Estonia	20	**Ireland**	23
France	20	**Poland**	23
Romania	20	**Portugal**	23
Slovakia	20	**Finland**	24
Great Britain	20	**Denmark**	25
Belgium	21	**Croatia**	25
Czech Republic	21	**Sweden**	25
Spain	21	**Hungary**	27

Source: authors

Most of the persons who make a demand for fuel purchases are not registered for VAT, for these persons the final price of the fuel is important, including VAT. The following table provides an overview of VAT rates that are not unified across the EU, and rates vary from 17% (Luxembourg) to 27% (Hungary).

The price of diesel fuel in € / liter with VAT and excise tax is shown in the figure (Fig. 2). The average price of diesel in the EU was € 1,346 in 2018, with the lowest price in the EU being € 1,101 / liter and the highest at € 1,519 / liter. It is particularly important to monitor the level of fuel prices in neighbouring countries. If we observe the situation in the Slovak Republic, the price level of diesel fuel was the 13th cheapest (1,251 € / liter), which is lower than the EU average. Neighbouring countries of the Slovak Republic have lower price, only Hungary is on the same price level. In general, it can be argued that the price of diesel is higher in the western part of the EU compared to the eastern part of the EU, with the exception of Luxembourg, which offers the lowest price of diesel throughout the EU.

Figure 2. Price of diesel fuel as of 4.3.2019 in EU



If we consider carriers registered for VAT payment, then it is necessary to monitor the price of diesel fuel without this tax (Fig. 3). In this case, the order of countries will change. E.g. the price of diesel fuel in Slovakia reaches a higher level than the average price of diesel fuel in the EU.

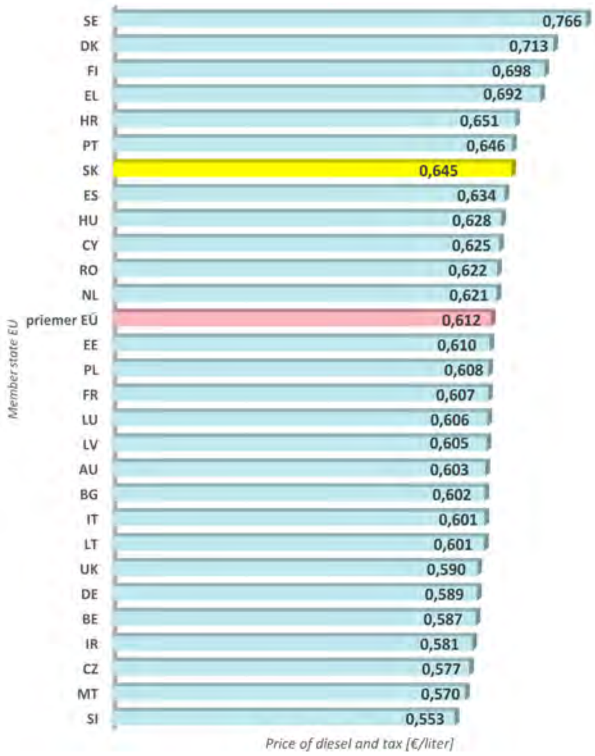


Figure 3. Price of diesel fuel excluding VAT and SD in Member States as of 4.3.2019

As the excise duty on mineral oils represents a high cost burden for carriers, in addition to optimizing the drawdown in individual countries, tax evasion related to the excise duty on mineral oils has also been reported. Hong – wei Z and wen-long (2004) and Gzang-ju W et al. (2016) are also addressing this issue, specifically the possibility of measuring tax evasion related to fuel sales and the possibility of detecting the amount of tax evasion related to value added tax on the fuel market in the Czech Republic. Braghin et al. (2006) and Stank et al. (2003) and Verros et al. (2005) evaluate existing standard methods used to measure tax evasion. At the same time, it has been shown that the methods are not suitable for determining the amount of tax evasion from the mineral oil tax by Kurdi et al. (2010). The authors proposed their own method for quantifying tax evasion on the basis of distributor pricing data obtained during 2012 and information obtained from a stakeholder survey. Borowiec et al. (2014) also in Montana, USA, the impact of the refund of excise duty on mineral oils on the state budget was observed, and Turkey also took into account the research, which analyzed the dynamics of fuel demand. The internalisation of externalities is also an important parameter in the field of mineral oil taxes by Richman and Moorman (2000).

As mentioned above, all EU countries have a mineral oil tax in place, accounting for about half of the net fuel price. Taxes are paid at the time of fuel purchase because of fast, easy and cheap collection. It should be noted that the mission of the tax is also to internalize all externalities caused by transport. It is possible that in some states externalities may arise than in another state, which may affect the amount of this tax. If mineral oil taxes were to be designed as an instrument for internalising all external effects, fuel should not be taxed at the same amount in each (EU) country, many congestions and accidents in the US and the UK. Several authors have addressed this issue, such as Vargo et al. (2004) and Debski et al- (2012). If the same territory is driven by a freight vehicle registered in two different countries, the same conditions should apply to both vehicles. Negatives that the tax should cover include air pollution, congestion, accidents, noise and climate change associated with greenhouse gas emissions. The mineral oil tax can be considered as a perfect tool for internalising the external costs of CO_2 emissions, because CO_2 emissions are closely related to fuel consumption. Accordingly, several countries advocate taxes on mineral oils for environmental reasons.

3. Research on excise tax refunds in the EU

Given that excise tax revenue is a national budget revenue, EU Member States strive to achieve maximum tax collection on their own territory. One option is tax refund as a means of motivating the use of fuel in the national territory. The following section provides an overview of the possibility of refunding part of the excise duty on mineral oils. These are vehicles with a payload of over 7.5 t, or vehicles of categories M2 and M3, i.e. buses. The excise duty on mineral oils can be refunded:

Belgium

In Belgium, part of the excise duty will be reimbursed in the case of refuelling with vehicles with a payload of over 7.5 t . Refunds are available up to 3 years after the date of withdrawal, but only if the client has a valid license. A copy of the RITA (TRP / VIT internal program) license must also be provided due to the need for the card number. The minimum annual refundable amount of TRP / VIT is € 260, quarterly € 1,000. Treasury documents are not acceptable.

France

Refunds are for vehicles with a payload of over 7.5 tons and for buses. The condition of TRP / VIT is that the carrier has to refill at least 5 600 liters every six months. Treasury documents are not acceptable.

Italy

Particulars of excise duty can be refunded when refuelling with vehicles with a payload of over 7.5 t and buses. An application is always required two years after the period. Treasury documents are not acceptable.

Slovenia

The reimbursement of part of the excise duty concerns the refuelling of diesel vehicles with a payload of over 7.5 tonnes and for buses. At least 6,500 litres per year are required. Cash receipts are only allowed if all details are given and paid by card.

Spain

In Spain, refunds are granted for vehicles over 7.5 t and buses.

Hungary

It is possible to refund the excise duty on mineral oils if we use diesel fuel with vehicles with a payload of over 7.5 t and buses. The refundable amount is HUF 7.00 / litre. Treasury documents are not acceptable.

The table (Table 2) shows the current rates of excise duty for countries where refunds are possible. By comparison, we find that Belgium has the highest return chance. and Hungary has the lowest refund amount. All rates are set by the customs offices in the countries concerned and by the competent European authorities.

Excise duty refunds may be up to 24 eurocent per liter, but carriers must reckon that excise tax refunds will only be made under certain conditions, eg. registration in a given country for the purpose of refunding excise duty, using fuel cards to a specific vehicle registration number, or according to the amount of liters consumed in a particular period.

Table 2. Country excise rates applicable to international transport companies

Country		*Rate €/liter*
Belgium		0,2476158
France	**Truck**	0,1775
	Autobusy	0,2175
Italy		0,21418000
Slovenia		0,06272
Spain		0,048
Hungary		7 HUF/l – 0,02*

* exchange rate of 04.03.2019 Source: authors

In the following part of the article we will also look at other states within the EU group. The table (Table 2) shows the excise duty on gas oil in the EU Member States .

When applying a refund, conditions arise in which some persons are charged at a different rate in a particular territory than others. States are trying to create conditions for entrepreneurs who would otherwise use fuel abroad to draw fuel on their territory.

4. Research on the impact of excise tax refunds on transport companies

The authors of the article conducted a research focused on Slovak carriers operating international road transport. Fuel costs can be classified as the highest variable cost items in road transport. Depending on the classification of transports, in particular as regards long-distance or short-distance transport, they may amount to up to 40% of the total annual cost. These costs can be influenced by the carrier in several ways, eg.:

- Selecting fuel suppliers;
- optimization of fuel consumption due to different fuel prices abroad
- the possibility of refunding excise duty on diesel in selected countries.

In the latter case, the possibility of reimbursement of part of the excise duty paid on diesel fuel would be able to reduce fuel costs. This subchapter evaluates the obtained data whether the possibility of cost reduction is also used by carriers in the Slovak Republic

In order to find out the situation in the Slovak Republic among carriers carrying goods or passengers within the EU on the topic of refunding excise duty on diesel fuel, the authors conducted a survey. The carrier's e-mail addresses have been obtained through the register of carriers on the website of the single road transport information system. Not all carriers provide a contact email in the carrier register, or the email address was invalid or the addresses did not receive mail. As a result, 300 emails were sent to carriers established in the Slovak Republic. Some have also taken into account the number of vehicles where the authors have focused on those who have indicated that they have licenses for more than 10 vehicles. Research has found that 17% of carriers are using a refund of excise duty from abroad.

Carriers that reimburse excise duty also use fuel in countries with significantly higher diesel prices than in the Slovak Republic. The figure below shows the proportion of countries from which carriers most frequently reimburse excise duty. Up to 31% of carriers reimburse excise duty from Belgium and 25% from Slovenia. At the same time, the diesel price in Belgium is the 5th highest price of diesel in the EU, yet carriers are refueling in that country (which size vehicles could transit without fueling), since the refund of excise duty state is getting below the EU level.

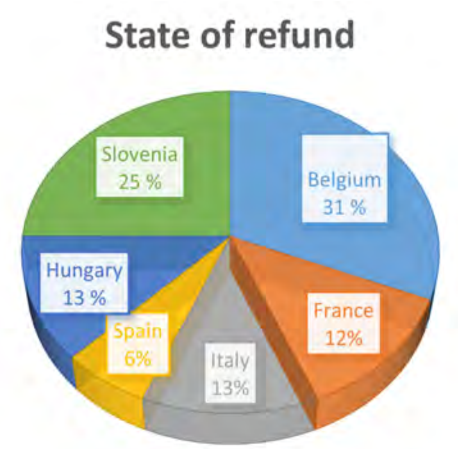


Figure 4. Answer the question about the refund location

The authors also found out how much money is reimbursed annually from the state. Slovak carriers most reimburse excise duty from Belgium (Figure 5). On average, carriers reimburse up to 75.000 € a year from Belgium.

Figure 5. Answers to the amount of the refund

The states in question cannot refund excise duty below € 330 per 1000 liters, which means that, at least, that part of the excise duty represents the revenue of the Belgian State budget. If, however, the refund was not allowed, the carriers would draw fueling states in another country through which the transport is carried out and in which the price of fuel is lower. If a refund were to be introduced in all EU countries,

we found out in the questionnaire what the refund system should avoid. Carriers consider the most important:

- Fast processing, quick refund, online submission
- do not impose a limit on the liters to be refunded;
- emphasize that the entire refund process is not unnecessarily complex;
- short processing time for applications,
- fast payback, online submission.

Today they do not create a level playing field in the EU common market with regard to the refund of excise duty on mineral oils. EU countries, when a neighboring state has lower diesel prices due to higher excise tax rates, encourages carriers to use fuel on their territory to get at least a minimum rate to their own budget. In our case, the average transport company in the Slovak Republic refunds from Belgium € 75,000 per year, which corresponds to a diesel volume of 276,750 liters per year. If only the minimum level of excise tax remains in the Belgian state budget, the income of one Slovak company is € 91,300 per year. The state budget revenue in other EU countries is reduced by this value. It should be borne in mind that with a fuel tank capacity of 750 liters, the carrier can optimize fuel consumption across the EU. It should be noted here that the system of excise refunds needs to be uniformly regulated across the EU.

5. Conclusions

This article deals with the issue of excise tax refunds within the EU. It points out that there are different conditions for persons operating in the EU single market. On the one hand, the EU points out that the introduction of this tax is necessary because of the burden on carriers of external transport-related costs such as accidents, emissions, noise, congestion and so on. Each EU Member State calculates excise duty rates according to its own methodology, often to meet the revenue of the state budget. It should also be noted that the EU sets a minimum level for this tax. Subsequently, in order to maximize the collection of tax in their own budgets, at the expense of tax collection in another country, states introduce tax refund systems. Tax refunds cannot be justified by reducing the external effects of transport. Excise tax refunds can be identified as a tool for distorting the EU common market. If the conditions were to be the same in the EU common market, the conditions for refunding excise duty should apply in all EU countries. Otherwise, there are conditions under which some Member States transfer tax revenues within EU Member States by means of refunds.

ACKNOWLEDGEMENTS

This publication was realized with support of Operational Program Integrated Infrastructure 2014-2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

REFERENCES

[1] Holguín-Veras J, Zorrilla JC, Thorson E (2005) Modeling commercial vehicle empty trips: theory and application. XVI International Symposium of Traffic and Transportation Theory (ISTTT), pp. 585–608, H. Mahmassani (Editor), Elsevier

[2] Hautzinger H (1984) The prediction of interregional goods vehicle flows: some new modeling concepts, ninth international symposium on transportation and traffic theory, VNU Science Press, pp 375–396.

[3] Fernández JE, de Cea J, Soto AO (2003) A Multi-modal supply–demand equilibrium model for predicting intercity freight flows. Transp Res Part B 37:615–640, doi: 10.1016/S0191-2615(02)00042-5

[4] Hong-wei Z, Wen-long W (2004) Safety analysis of over-size and over-load in road transport. J Highw Transp Res Dev 21(3):132

[5] Guang-ju W, Juan S, Bing-nan G (2016) Analysis of changes in the new version of GB 1589. AUTO SCI-TECH 4:24–29

[6] Considerations of policy for perfecting road freight transport market management. J Highw Transp Res Dev 28(2):154–158

[7] Debski, H., Koszalka, G., Ferdynus, M.: Application of FEM in the analysis of the structure of a trailer supporting frame with variable operation parameters. Eksploatacja i Niezawodnosc—Maintenance and Reliability. 14, 107–114 (2012)

[8] Braghin, F., Cheli, F., Melzi, S., Resta, F.: Tyre wear model: validation and sensitivity analysis. Meccanica 41, 143–156 (2006)

[9] Stank, T.P., Goldsby, T.J., Vickery, S.K., Savickie, K.: Logistics service performance: Estimating its influence on market share. Journal of business logistics, vol. 24, no. 1, 27–55 (2003)

[10] Bowersox, D.J., Closs D.J., Cooper M.B.: Supply Chain Logistics Management, McGraw-Hill/Irwin, New York, (2002)

[11] Verros, G., Natsiavas, S., Papadimitriou, C.: Design optimization of quarter-car models with passive and semi-active

suspensions under random road excitation. J. Vib. Control 11, 581–606 (2005)

[12] Kurdi, O., Rahman, R.A.: Finite element analysis of road roughness effect on stress distribution of heavy duty truck chassis. Int. J. Technol. 1, 57–64 (2010)

[13] Borowiec, M., Rysak, A., Betts, D.H., Bowen, C.R., Kim, H.A., Litak, G.: Complex response of the bistable laminated plate: multiscale entropy analysis. Eur. Phys. J. Plus 129, 211 (2014)

[14] Richman, J.S., Moorman, J.R.: Physiological time-series analysis using approximate entropy and sample entropy. Am. J. Physiol. Heart Circ. Physiol. 278, H2039–H2049 (2000)

[15] Vargo, S. L., Lusch, R. F.: Evolving to a new dominant logic for marketing. Journal of Marketing, no. 68, January, 1–17 (2004)

DOI: 10.26552/tac.C.2021.2.4

Possibilities of the Use of Multicriterial Mathematical Methods in Building Customer Relations in the Area of Logistics and Transport Services

Miloš Poliak[1], Iwona Ewa Tomaszewska[1], Miroslava Mikušová[1]

[1] Faculty of Operation and Economics of Transport and Communications, University of Žilina, Žilina, 010 26, Slovakia,

Abstract Background: In actual world the ability to analyse multifaceted issues and interpret results is one of the most important competences for creating and evaluating decision-making variants. The increase in the importance of these competences is determined by many factors of socioeconomic life, including the development of the information society, with a particular focus on the dynamic generation and processing and analysis of large amounts of information (BigData) using, inter alia, cloud computing necessary to support processes e.g. in the implementation of transport services, virtual and augmented reality, the industrial Internet of things, the development of industry 4.0, which provides the basis for the creation and integration of conjugated information and operational technologies, creation of cyber physical systems, cybersecurity issues, implementation of artificial intelligence or block chain. Persons making decisions, assumptions and scenarios need to use techniques and tools that describe the facilities and phenomena studied in a comprehensive manner, while allowing for the rapid and practical preparation of development and decision-making plans. This is especially important in the area of logistics and transport services.
Objectives: This study aimed to explore possibilities of application of multi-criterial mathematical methods in the area of logistics and transport services.
Method: An analysis of multi-criteria decision methods´ algorithms was used to identify the most convenient methods.
Results: Practical examples of identified methods are provided in vehicle distribution systems.
Conclusion: This study revealed that the use of ELECTRE, AHP, PROMETHEE and UTA methods is the most convenient in the investigated area.

Keywords decision making; multi-criteria analysis; logistics; transport services; algorithm.

JEL Classification: R48; H40

1. Introduction

Decision-making practice focuses on weighing alternatives that meet a set of desired goals. Each decision includes the element of discovery, irrational randomness and economic, social, political, organizational, managerial and other effects. The decision is to choose one of them.

In any decision-making problem, there is at least one optimal decision, for which it can be objectively determined that there is no other better decision while remaining neutral with regard to the decision-making process. The problem is to choose the alternative that best meets the complete set of goals. Making choices and decisions is one of the basic human activities. The decisions that a person makes not only determine the shape of his personal and family life, but to some extent affect the history of certain environments and communities.

Mature decision-making is the art of making the right choices. No person can avoid making decisions, because everyday life constantly puts us in the face of facts and events that demand from us to take an attitude or make certain choices. Decision-making in the strict sense is only when such decisions are made by a man in a conscious, purposely and voluntary manner. This means that before making a decision, he or she can see alternative variants for action at any given time, and that decision-making is guided by a clearly defined objective. The majority of the population has been found to be accustomed to existing schemas of thinking and solving problems [1]. If we learn other ways of thinking, we will be able to find new solutions and better prepare for the constant change of conditions around us.

The initiators of the decision, solving the identified problems, try to express with a single aggregate criterion all the relevant consequences of the problem. We are then dealing with a single-criteria analysis in which each potential variant is assessed against one selected a priori criterion, e.g. cost volume, profit, profitability, benefit.

In solving this problem, we use various ways, methods, e.g. linear programming, parametric programming, targeted programming, marginal analysis, stochastic programming, nonlinear programming, econometric methods, game theory and others. This procedure is justified only in simple cases, as a single criterion is not fully reliable, acceptable and exhaustible, i.e. there is no property that a coherent family of criteria should have [2].

Multi-criteria decision-making (MCDM) is a development of single-criteria analysis. It allows for the formulation of a coherent family of criteria as an instrument for an understandable, acceptable and comprehensive set of arguments. The approach expressed should ensure that preferences are developed, justified and transformed into guidelines for the decision-making process.

Supporting multi-criteria decisions requires the participation of a number of adjudicators in the decision-making process. The assumption is based on observations of the behaviour and position of the various participants, which result from a different perception of reality and the processes taking place there [3]. They also result from the fact that each person represents a different world of values, and the positions of individual participants are built on different, sometimes conflicting, evaluation systems. Consequently, a multi-criteria approach to decision-making is formulated.

Classical multi-criteria methods are based on the assumption that the assessment of decision-making variants against criteria and the weighting of criteria are known precisely and expressed by real numbers. In practice, there are situations where it is difficult or even impossible to define precise assessments of decision-making variants. In such situations, the assessment of variants and/or the weighting of the criteria may be expressed by means of interval numbers [4], fuzzy numbers or ordered fuzzy numbers (5), among others.

The key elements of the practical application of MCDM methods are the determination of reliable weightings of the criteria as they have a key impact on the choice of the final variant [6]. Many applications of MCDM methods use so-called subjective weights, defined by project promoters or experts, reflecting their subjective feelings and preferences.

In situations where it is not possible to determine reliable weights, one can turn to objective balances, which are determined on the basis of a decision matrix. One method for determining objective weights is the entropy-based method. As the assessment of decision-making variants against criteria is a range, the weightings of the criteria should also be ranges. In the literature, methods can be found for determining the weighting of criteria using entropy, which is extended to compartmental entropy [7] and to entropy based on ordered fuzzy numbers [8].

2. Literature review

The ability to analyse multifaceted issues and interpret results is one of the most important competences in the complex process of creating and evaluating decision-making variants. The increase in the importance of these competences is determined by many factors of socio-economic life. Highlights include the development of the information society, with a particular focus on the dynamic generation and processing and analysis of large amounts of information (BigData) using, inter alia, cloud computing necessary to support processes e.g. in the implementation of transport services, virtual and augmented reality, the industrial Internet of things, the development of industry 4.0, which provides the basis for the creation and integration of conjugated information and operational technologies, creation of cyberphysical systems, cybersecurity issues, implementation of artificial intelligence or blockchain.

Persons making decisions, assumptions and scenarios need to use techniques and tools that describe the facilities and phenomena studied in a comprehensive manner, while allowing for the rapid and practical preparation of development and decision-making plans in the areas analysed.

The issue of a multi-criteria approach concerns the following issues: choosing the best variants (alternatives) for the criteria considered, organizing objects from best practices to the worst, and sorting (classifying) variants according to pre-established criteria. Multi-criteria methods are mainly used to provide decision-makers with a tool that, in the event of a number of conflicting decision-making criteria, will enable a rational decision to be made.

Multi-criteria analysis is used to support decision-making in situations where the choice is made between multiple variants. It is important to select the assessment criteria accordingly and to assign the weights appropriately. This means that, depending on the issue, the criteria should reflect different aspects such as costs, time, inter-entity dependencies, market trends, closer and further environment requirements, implementation opportunities and others. The purpose of the analysis is to select an variant adapted from the point of view of the criteria adopted [13], [14]. When performing a multi-criteria analysis, one adopts a certain set of specific solutions:

$$W=\{W\_i: i=1,2,3 \ldots,n\} \tag{2}$$

and a set of criteria:

$$K = \{K_i: j = 1,2,3 \ \ldots, m\} \tag{3}$$

according to which the different variants will be assessed. Then, for each criterion, the value X_{ij} needs to be specified. The value of X_{ij} is a measure of variant W_i according to criterion K_j.

All assigned values are placed in a structured data matrix:

$$Xij = \{x_{ij}: i = 1,2,3 \ \ldots, n; \ j = 1,2,3 \ \ldots, m\} \tag{4}$$

DOI: 10.26552/tac.C.2021.2.4

in which the *i*-th row shows the values of the variant and according to subsequent (all) criteria, and *j*-th column - the values of subsequent (all) variants according to the specified criterion *j* [15]:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \cdots & \cdots & \vdots \\ x_{i1} & \cdots & x_{11} & \cdots & x_{im} \\ \vdots & \cdots & \cdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \quad (5)$$

Each of the criteria needs to have weight assigned to it. When selecting evaluation criteria, one can use both measurable and non-measurable parameters, which will describe variants without their quantitative evaluation. In addition, both quantitative and qualitative criteria can be used using multi-criteria. When choosing qualitative criteria, they must be quantified in order to carry out the comparison. Publications [15], [16] described a number of ways of criteria standardising. The standardisation of Peldschus, Van Delft and Nijkamp [15], Weitendorf [17]. can be used.

Multi-criteria methods were developed in a distributed manner, what affects ambiguity in the classification of studies. The division of multi-criteria decision support methods pointed out by many specialists [18] distinguishes:

- methods of multi-attribute utility theory, called synthesis methods to a single criterion, disregarding incomparability [19]. A group of methods, derived from the American tradition and based on the multi-attribute utility theory [20], consists in aggregating different criteria (points of view) into a single utility function that is maximized [18]. Eventually, multiple criteria (attributes) are reduced to a single global criterion. The *U* usability function can therefore be saved as following [21]:

$$U = U(f) = U(f_1, f_3, f_3, \quad \ldots\ldots, \; f_n) \quad (6)$$

where: f_1, f_2, f_3,, …f_n are individual criteria.
Multi-attribute utility theory is based on the assumption that all variants of a given problem are comparable. It follows from that thesis that, for each pair of variants, the decision-maker will always prefer one of them or consider them equivalent [21]:

aPb, i.e. a is preferred over b,
bPa, i.e. b is preferred over a,
aIb, i.e. a and b are equivalent (7)

Preference and equivalence relationships are formulated according to [21]:

$$aPb \Leftrightarrow U(z_a) > U(z_b)$$
$$aIb \Leftrightarrow U(z_a) = U(z_b) \quad (8)$$

where: z_a and z_b respectively are images of variants a and b in the criteria space, $U(z_a)$ and $U(z_b)$ are respectively usability values of variants *a* and *b*.

The properties of preference relationship *P* and equivalence *I* [21] are defined:

aPb-bPa, i.e. P is asymmetric,⇒
aIa, i.e. I is callback,
aIbbIa, i.e. I is symmetrical,⇒
aPb and bPc aPc, i.e. P is transitive,⇒
aIb and bIc aIc, i.e. I is transitive.⇒ (9)

The multi-attribute utility theory methods include UTA [22], [23], and AHP [24], [25], [26].

- methods based on the preference relations are called preference synthesis methods taking into account incomparability (27). Methods based on the preference relations were developed by B. Roy [28], [29], [19], [30], [31], [32], [33], [34], [35].

In the methods, the decision-maker's preferences are modeled by means of a preference relation, which allows for the incomparability of variants, i.e. a situation in which the decision-maker cannot indicate similarities and differences between variants. It is neither able to consider variations as equivalent nor indicate the better of the two variants.

The *S* preference relation is a binary relationship defined in variant set *A*. Depending on the *aSb,* the information on the decision-maker's preferences, the quality of the assessments of the different variants and the nature of the problem is available. It provides enough arguments to consider that variant *a* is at least as good as *b,* while lacking significant information to reject this assumption.
The definition of the preference relation *S* is formulated as the sum of relationships of equivalence I and preference *P*, i.e.: *S=P I*∪. On the basis of the *S* relation, it is possible to determine the decision-maker's preferences in accordance with [36]:

$$aPb \Leftrightarrow aSb \text{ and } -bSa$$
$$aIb \Leftrightarrow aSb \text{ and } bSa$$
$$aRb \Leftrightarrow -aSb \text{ and } -bSa \quad (10)$$

where: *aRb* is the relationship of incomparability between variants *a* and *b*.
The relation (10) results in the following characteristics of preference relationship *P* and equivalence *I* [36]:

aPb⇒ –bPa, i.e. P is asymmetric,
aIa, i.e. I is callback,
aIb ⇒ bIa, i.e. I is symmetrical. (11)

The preference feature has dependency-defined properties [36]:

aSa, i.e. S is callback,
aSb and bDc ⇒ aSc,
aDb and bSc ⇒ aSc, (12)
$aI_jb \; \forall_{j} \neq q$ □ $aSb \Leftrightarrow aS_qb$

where: *D* – relationship of dominance, I_j – equivalence relationship due to criterion j, S_q – preference relation due to *q* criterion.

Among the methods based on preference relation we distinguish: Electre I –IV [], [27], [28], [38], [39], Promethee I and II [37], [40], [41], [42], and Oreste [43] [44]. A separate group consists of methods that are a combination of a methodology based on the preference relation, as well as a multi-attribute theory of usability. The methods Idra [45], Mappac [46], Pragma [47] are included in the group.

- interactive methods, called local assessment dialogue methods based on the trial and error approach of individual iterations [30], [31]. A common feature of methods based on the trial and error approach in individual iterations is the interlacing of the computational and the decision-making phase. As a first step, the decision maker obtains pareto-optimised solutions or sample solutions. In the second, the replies received are verified on the basis of preferential information [48], [49], [51]. One can highlight the following methods in this group:
  - search-oriented, e.g. LBS [52], [53], [54], STEM [55],
  - learning-oriented [56].

Among the methods which correspond to the classification criterion of the purpose of the decision-making process one can distinguish [57], [58]:

– multi-criteria selection methods (optimising),
– multi-criteria classification (sorting) methods,
– multi-criteria serial (ranked) methods.

In view of the wide variety of multi-criteria decision support methods available, each with specific advantages, disadvantages and limitations, for each of the issues considered, it is necessary to carry out a detailed qualitative analysis in order to select a technique that is appropriate to the decision-making problem in question. We focussed our investigation on the convenience of these methods for their use on the area of logistics and transport services. The basic overview of the main findings is presented in the following text.

MCDMs are used in many areas and segments of the economy. Depending on formulating the problem and the nature of the issues addressed, there are, identifiable in particular in scientific reports and experimental reports, preferences for the use of different multi-criteria methods. There are analyses on environmental [88], design [81], [89], and industrial [90] issues. The issue of multi-criteria decisions covering sales and marketing is reflected in [91], human resources management, inter alia, in [92], [93], production management [94], and transport and logistics [95], [58], [96], [97].

An analysis of the problems in publications compared to the preferences of authors and users revealed trends in the use of groups of multi-criteria methods. Mr Saaty described the use of the AHP method to address multi-criteria transport decision-making problems, including m.in. choice: the route for commuters, the most advantageous combination of routes to pittsburgh's new international airport, and the most advantageous mode of transport taking into account the cost-benefit analysis [24]. Article [25] characterises the use of the AHP method to address the multi-criteria decision-making problem of transport investment for the transport system in the Bosphorus Strait. The AHP method and ELECTRE III method were used to determine variant weights and calculate the parameters of the multi-secretarial objective function and to solve the decision-making problem related to the transport investment for the transport system in Poznań [98]. J. Żak used ELECTRE III as a decision support tool to solve the problem of decision-making allocation of vehicles to the tasks of the transport company [99]. An assessment of the environmental impact of transport using the ELECTRE III method is described in the article [85]. Source [100] presents a solution to the decision-making problem of the rank of transport service providers for a company operating in public road and rail transport using the multi-criteria PROMETHEE method. The PROMETHEE method was used to solve the multi-criteria problem of choosing the route between Belgrade and Birmingham [101]. E. Jacquet-Lagreze and J. Siskos used the UTA method to solve the multi-criteria problem of car serialing decision-making [102]. At work [103] the decision-making problems in transport systems are described.

3. Research design and methodology

Based on the analysis of the literature, no research results focused on CRM were found. When implementing CRM, it is important to identify customer expectations and to achieve the best possible customer satisfaction. It is important to note that there are differences in the provision of services and in the supply of tangible goods. The aim of this research is to identify which methods of multicriteria evaluation can be used in the implementation of CRM in the conditions of companies providing transport services. The research methodology is based on the evaluation of individual methods of multicriteria evaluation in terms of usability in the evaluation of customer care in the provision of transport services.

Given the different uses of MCDMs to solve multi-criteria decision-making problems, it is important to choose a tailored method of supporting decisions. The concept of choosing the MCDM method for the specificity of the multi-criteria decision-making problem involves carrying out a step-by-step approach to the solution by performing the following (in order):

– identification of the decision-making situation – the current decision-making situation is assessed, including both an informal and a formal assessment of the functioning of the system, e.g. SWOT analysis,
– detailed MCDM analysis – axiomatic analysis allows you to assess the specificity of the methods, identify their weaknesses and strengths. The arrangement of methods supports the process of adapting the method to the specificities of the analyzed decision-making problem. The indication of the MCDM method shall affect the correct modelling of the decision-making situation and the appropriate interpretation of the results obtained,
– analysis of aspects of method selection – analysis of aspects of matching decision-making problem and MCDM method and between the method and preferences of the decision-maker,
– comparison of the results of the analysis – the assessment of the matching of the MCDM method with the

specificity of the decision-making problem and to the decision-maker's preferences are compared with each other. The conclusions resulting from the comparative analysis of the information obtained are the basis for recommending the use of the method in the decision-making situation under analysis,

– method selection.

Based on the performed research the most convenient methods for identification and description of the specificities of logistics and transport services are ELECTE III, AHP, PROMETHEE I and UTA.

This section is providing detailed description of previously identified methods, that make possible their effective application in the area of logistics and transport services.

The ELECTRE III calculation algorithm includes three steps:

I. the design of the evaluation matrix and the definition of the adjudicator's preference model – defining a set of variants A and defining a coherent family of criteria F. For all the variants the values of subsequent criteria functions fj are determined. With the equivalence *qj*, preferences *pj* and veto *vj* thresholds and coefficients of importance *wj*, for each criterion j, the adjudicator's preference model is defined. This is subject to the condition,

$$q\_j<p\_j<v\_j \quad (13)$$

II. design of the preference relation – for each pair of variants (*a, b*) the following shall be determined:

a. conformity factors *cj* (*a, b*) which determine to what extent, according to criterion *j*, variant *a* is at least as good as *b,* as described by the dependency:

$$c_j(a,b) = \begin{cases} 1 \text{ if } f_j(a) + q_j(f_j(a)) \geq f_j(b), \\ 0 \text{ if } f_j(a) + p_j(f_j(a)) > f_j(b) \\ \text{linear function of 0 and 1 value} \end{cases} \quad (14)$$

b. conformity index:

$$C(a,b) = \frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b) \text{ gdzie } W = \sum_{j=1}^{n} w_j \quad (15)$$

c. non-conformity factors *D*(a, *b*) which determine to what extent, according to criterion *j,* variant *a* is at least as good as *b,* as described by the dependency:

$$D_j(a,b) = \begin{cases} C(a,b) \text{ jeżeli } D_j(a,b) \leq C_j(a,b), \\ C(a,b) \prod_{j \subset (a,b)} \frac{1-D_j(a,b)}{1-C_j(a,b)} \end{cases} \quad (16)$$

where: *J(a,b)* is a set of criteria for which $D_j(a,b)>C(a,b)$.

III. use of the preference relation – ordering variants on the basis of the preference degrees obtained *S (a, b)* according to the condition:

$$\lambda = \max S(a,b) \quad (17)$$

Only those pairs of variants *(a, b)* for which *S(a, b)* is located in close proximity to *λ* undergo the analysis. Position is determined by the difference *λ* – *s*(*λ*), where *s*(*λ*) is the so-called cut-off level. The so-called qualification factor of each variant *Q*(a), i.e. the difference between the number of variants that the variant is superior to and the number of variants in respect of which case *(a) is* classified below, is calculated on the basis of the *λ* value.

On the basis of the descending and ascending preorder, a final ranking of solutions is prepared, based on the following principles:

- variant a is considered superior to variant *b (aPb)* if at least one of the complete preorders a is placed before b and in the other *a* is at least as well classified as *b,*
- variant *a* is evaluated equally against *b (aIb)* if both variants belong to the same class in each of the two ranks,
- variants *a* and b are incomparable (aRb) if variant *a* is in a better position in one of the two series than *b* in the ascending preorder, while variant b is in a better position than a in the second rank.

Between the variants there may be situations: equivalence – *I*, preference – *P* and incomparability *R* [99]. In the ranking matrix, the relations are shown between pairs of variants and written in the form of symbols: equivalence – *I*, preference – *P*, inverse of preferences – (*P*) andincomparability – *R*.

The AHP algorithm assumes that actions are carried out involving:

a. constructing a hierarchical structure of the decision-making process, by setting levels: the objective of the decision-making process, which may be, for example, to organize decision-making variants from best to worst and to choose the preferred variant (level 0) – criteria and evaluation sub-criteria (level 1), decision-making variants (level 2).

b. defining the decision-maker's preferences – at each level of the hierarchy, decision-making participants grant relative assessments of importance (on a scale of 1 to 9 points) for pairs of criteria and decision-making variants, indicating individual preferences of the solution. The more preferred (more important) an element is, the higher its score. All factors are compensatory, i.e. the rating value for a less important (less preferred) element in a given pair is the inverse of the value assigned to the more important (more preferred) element. The resulting sets of comparisons are presented in pairs in evaluation matrices, where rows and columns have further criteria, sub-criteria (specified for each criterion) and variants (specified for criteria and sub-criteria). The direction in which preference information is written in matrices is always the same, i.e. the relation of the element in the row to the element in the column is presented.

c. calculation of standardized evaluations of the validity of hierarchy elements – based on the evaluation matrix, an estimate of the validity ratings of individual elements of the hierarchy is used. To this end, the so-called problem of seeking the value of the matrix's own value is solved.

The validity ratings are then normalized, i.e. their sum at each level of the hierarchy is 1.

d. study of global matrix consistency – checking the logic and homogeneity of preferential information provided by the decision-maker. For this purpose, a *consistency ratio* (CR) shall be used, the value of which shall not exceed 0,1. If the value of the cohesion index exceeds 0,1, then it is necessary to verify the preferential information provided by decision-makers, as it is too inconsistent or a mistake has been made e.g. when entering data. In such a situation, the decision-maker's preferences are redefined.
e. variant final rank – standardised weights of variants, sub-criteria and criteria are aggregated using an additive utility function that synthesizes the weight shares of elements from each level. Scales represent an element's share of the global decision-making goal. The utility I of this variant U_i(t-*2*) appearing in the hierarchy at level t - *2*, is calculated as the sum of the product weights of the individual elements occurring on the road from each branch of the hierarchy to which the variant is associated and (level *t - 2),*through sub-criteria (level *t - 1)* and criteria (level *t).* Utility U_i(t- *2*) is an aggregated assessment, the value of which should be determined from dependencies:

$$U_{i(t-2)} = \sum_{j=1}^{nt}\sum_{l=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{l} w_{i(t-2)}^{k(t-1),(j,t)} \cdot w_{k(t-1)}^{j(t))} \cdot w_{j(t)}^{0}$$

where: (18)

$w_{i(t-2)}^{k(t-1),(j,t)}$ – standardised assessment of the validity

(weight) of the hierarchy *element* and (variant) *at level t-2* relative to the hierarchy element *k* (sub-criterion) at level *t-1* and the hierarchy element *j (criterion)* at level *t*,

$w_{k(t-1)}^{j(t))}$ – standardised assessment of the importance

(weight) of hierarchy element *k* (sub-criterion) *at level t-1*, relative to the element of hierarchy *j* at *level t* (criterion),

$w_{j(t)}^{0}$ – a standardised assessment of the importance

(weight) of the hierarchy element *j* at level *t* relative to the level *0* hierarchy element (decision-making objective).

As a result of the actions carried out, it prepares a summary of variants from best to worst, according to the calculated values of their usefulness, from the largest to the smallest. Relationships that may occur between variants in the end hierarchy can be indexed as: equivalent to *I* and preferred *P*. The scheme of multi-criteria analysis in the PROMETHEE method is carried out in accordance with the procedure:

– comparing variants according to individual criteria using the preference functions reflected in the equation:

$$D_j(a,b) = \begin{cases} H(x) \text{ if } f_k(a) > f_k(b), \\ 0 \text{ if } f_k(a) \le f_k(b) \end{cases} \quad (19)$$

where: $x = f(a) - f(b)$, $.0 \le H(x) \le 1$

– preference aggregation in the form of preference *π(a, b)* is expressed by a dependency:

$$\pi = \sum w_k \cdot P_k(a,b) \quad (20)$$

– ordering variants based on preference flows φ^+ and φ^- :

$$\varphi^+(a) = \sum_{x \in A} \pi(a,x)$$

$$\varphi^-(a) = \sum_{x \in A} \pi(a,x) \quad (21)$$

The $\varphi^+(a)$ is an indicator of a variant preferences and compared to other variants. The $\varphi^-(a)$ is an indicator of the lack of acceptance (lower rating) of *a* in relation to the other variants. The PROMETHEE I method allows for organizing a set of decision variants by using a preference relation. In the case where variant *a* is not preferred by variant *b*, shall be written according to:

$$a \succcurlyeq_s b \text{ if } \varphi^+(a) \ge \varphi^+(b) \wedge \varphi^-(a) \le \varphi^-(b) \quad (22)$$

If variant *a* is not preferred by variant *b* and at the same time *variant b* is not preferred by variant *a*, then *a* is equivalent to *b* as is left:

$$a \succcurlyeq_s b \wedge b \succcurlyeq_s a \Rightarrow a \approx b \quad (23)$$

The preference relation is used to draw up a list of decision-making variants (partial ordering). To check whether there is a resilient relation of domination :

$$a \succcurlyeq_{sII} b \text{ if } \varphi(a) \ge \varphi(ab) \quad (24)$$

dependencies must be resolved:

$$\min_{w \in W}(\varphi(a)) - \varphi(b) \ge 0$$
$$\min_{w \in W}(\varphi(b)) - \varphi(b) \ge 0 \quad (25)$$

Procedure for determining resistant relationships of dominance in PROMETHEE I. method:

For all $i = 1, \dots, m, \quad j = 1, \dots, m$

designate $min_1(i,j)$ according to

$$\min_1(i,j) = \operatorname{argmin}(\varphi^+(a_i) - \varphi^+(a_i) \text{ for } w \in W \quad (26$$

DOI: 10.26552/tac.C.2021.2.4

$$\varphi^-(a_i) \le \varphi^-(a_j) \quad)$$

For all $i = 1, \dots, m, \quad j = 1, \dots, m$

designate $min_2(i,j)$ according to

$$\min_2(i,j) = \operatorname{argmin}(\varphi^+(a_i) - \varphi^+(a_i) \text{ for } w \in W \quad (27$$

$$\varphi^-(a_i) \ge \varphi^-(a_i) \quad)$$

For all $i = 1, \dots, m, \quad j = 1, \dots, m$

check if there is *a* relation $a_i \succcurlyeq w_{wI} a_j$ with

$$a_i \succcurlyeq w_{wI} a_j$$

$$if\ min_1(i,j) \ge 0, \quad \text{and} \tag{28}$$

$$min_{12}(i,j) > 0\ or\ there\ is\ no\ i\ min_2(i,j) \le 0$$

Utilits Additives type (UTA) methods are based on minimizing utility error using a linear programming model. The UTASTAR method [105] assumes the objective to minimize the distribution (dispersion) of errors, the UTADIS method determines two error values: $\rho_k^+\ and\ \rho_k^-$ indicating, respectively, a violation of the lower and upper end of the utility function of the alternative group by the k-th decision-making variant. UTADIS I assumes equal optimality criteria when creating an additive value classification model, UTADIS II is based on minimizing the number of poorly classified alternatives, UTADIS III simultaneously minimizes misclassified alternatives and maximizes the measure of good classification (distance of alternatives from value thresholds). The UTA method procedure includes:

a. identification of input data – the input data necessary for the calculation procedure is prepared, i.e.: a finite set of variants *A*, a coherent family of criteria *F*, the arrangement of parts of the set *A* – *A'*, which is at the same time the definition of the preference model. The preference model uses relations of preference P and equivalence *I*.
b. constructing usability functions – a usability function is built on the basis of input:

$$U(a) = \sum u_i(f_i(a)) \tag{29}$$

where: $w_{(j)}$, the weight (conversion or compensation factors) of criterion *j* determining how many units of a given criterion *j* compensates the unit of another criterion. The values of the criterion functions ($U_j(u_j^i)$) are defined in order and, in points u_j^i. Then linear interpolation U_j between these points is carried out on the basis of dependencies (30):

$$U_j(z_j) = U_j(u_j^i) + \frac{z_j - u_j^i}{u_j^{i+1} - u_j^i}\left[U_j(u_j^{i+1}) - U_j(u_j^i)\right] \tag{30}$$

If the number of elements in the set is relatively small, then these elements take the value u_j^i, which allows after the transformation to save the dependency (30) as:

$$U(a) = \sum U_i(x_i^a + \delta(a) \tag{31}$$

where: $x_j^a = f_j(a)\ and\ \delta(a)$ is an error related to estimation of value U (*a*).

c. final variants' ranking – all variants are eventually ranked from best to worst according to the obtained partial values of utility function *U*(*a*). The measure of conformity of the summary statement, generated from the *U* utility function obtained, with the order set by the decision maker (standard order *A'*) is the amount called the Kendall coefficient – *τ* determined by the following formula:

$$\tau = 1 - 4 \cdot \frac{d_k(R, R^*)}{m(m-1)} \tag{32}$$

where:
R – matrix of size [mm], associated with the order set by the adjudicator,
R^* – matrix of size [mm], associated with the order specified by the utility function,
$d_k(R, R^*)$ – Kendal's distance, which determines the differences between the different elements R and R^*.

4. Disscusion of Result

The issue of the vehicle distribution system is based on the functioning of car companies cooperating with subcontractors, e.g. car dealers. Regardless of the location of the production facilities, the automotive industry has a characteristic of the need to distribute and transport manufactured vehicles from manufacturer to recipient. The reality of the industry and the market demand that there must be indirect entity between the first and the last entity, without which the process could not be properly implemented. Therefore, the main links identified in the vehicle distribution system are the manufacturer, importer, dealer and consignee [106].

For the purpose of completing this task, the following assumptions were formulated:

– the movement of vehicles in the distribution system takes place in exactly the following order:
manufacturer → importer → dealer → user;
– the movement of vehicles in the system is known and predetermined;
– the number of vehicle manufacturers is known and production facilities may be located in different locations (e.g. countries or continents);
– manufacturers receive orders for individual vehicles directly from importers, in a specific technical specification;

– the customer cannot order the vehicle directly from the manufacturer, bypassing the other links in the chain.

The issue for the recipient is the selection of a suitable vehicle (means of transport) to carry out certain transport tasks. The customer has the opportunity to order any vehicle on sale on a given market (which is offered by a local importer). Before choosing the right means of transport, the user must also make certain assumptions:

a. specify the type of transport task to be carried out,
b. specify the time for which they intend to use the vehicle,
c. determine the degree of wear of the vehicle concerned, i.e. determine the average annual mileage of the vehicle to be carried out during the performance of the transport tasks.

For the purposes of presented investigation, it is assumed that the customer reports to the dealer, who has the means of transport on offer to all importers operating on the market concerned and sets out the requirements which, in their opinion should be met by the means of transport. When configuring the means of transport, the user will determine its technical and technological parameters, inter alia: volume of cargo space, payload, permissible total weight, type of fuel supply, emission standard, expected fuel consumption per 100 km.

The purpose of the vehicle distribution system is to provide potential customers with transport vehicles enabling the defined transport tasks to be carried out. It is required that the vehicle distribution system has a defined structure and operates on the basis of known organisational assumptions subordinated to the provision of vehicles to users.

4.1. Guidelines for multi-criteria assessment

For the purpose of the analysis, partial evaluation indicators were identified: the duration of the transport service, expenditure on the use of the vehicle e.g. depreciation resulting from the loss of value of the means of transport during the execution of transport tasks, related to the projected annual mileage of the car, maximizing the average daily working time of the means of transport, maximizing the use of means of transport. Depreciation cost is calculated according to dependency:

$$K(d(i),t(i)) = \frac{C^z(i) - RV^b(d^b(i),t^b(s)) \cdot RVC(d(i),t(i))}{m^b(i)} \tag{33}$$

where:

$K(d(s),t(i))$ – the cost of depreciation *i-th* means of transport taking into account the annual mileage and duration of the service in Eur/km,

$C^z(s)$ – the cost of purchase *i* – this means of transport,

$RV^b(d^b(i),t^b(i)) \cdot RVC(d(i),t(i))$ – the resale value of the means of transport after the transport task has been carried out,

$m^b(i)$ – the total mileage of *i-th* means of transport.

The cost of tyres $K_{o\ in}$ Eur/km of the *i-th* means of transport during the life of the vehicle is recorded by a dependency:

$$K_o(m(s),t(s)) = \frac{(2s_c \cdot k_w(a) + l_o(b) \cdot (o_l(a) + o_z(a)) + k_{po}(b,i) \cdot n_s)}{2m(i)} \tag{34}$$

where:

$o_l(a)$ – the cost of purchasing a summer tyre in size *a*,

$o_z(a)$ – the cost of purchasing a summer tyre in size *a*,

$k_w(a)$ – the cost of replacing one tyre in size *a*,

$l_o(b)$ – number of tyres,

$k_{po}(b,i)$ – the cost of storing one set of tyres for one season,

s_c – number of tyres operated simultaneously in service,

n_c – fixed number of tire replacement periods,

$m(s)$ – the total mileage of the *s-th* means of transport.

The average daily working time indicator $L(i)$ was formulated as (35). The high value of the indicator $L(i)$ can compensate for losses resulting from the low rate of use of means of transport.

$$L(i) = \frac{t_g(s)}{d_p(s)} \tag{35}$$

where:

$t_g(i)$ – working time in hours of *i-th* means of transport,

$d_p(i)$ – number of working days of *i-th* means of transport,

The rate of maximisation of the use of means of transport is calculated as the quotient of the working days of the means of transport (involvement in the performance of transport tasks) and the days at our disposal:

$$L_{max}(s) = \frac{d_p(i)}{30\ t(i)} \tag{36}$$

where:

$d_p(i)$ – number of working days of *i-th* means of transport,

$t(i)$ – the time of disposal of *i-th* means of transport in months.

4.2. Local distribution model is the operational problem

Attention was also drawn to the issue of route planning as part of the strategic arrangements described in [107]. The issues raised concern in particular the issue of determining the shortest route and/or minimum journey time in order to reduce the total cost of forwarding. Assuming that the total cost is derived from the length of each route, the calculation of the total cost of transporting

DOI: 10.26552/tac.C.2021.2.4

consignments on the route marked with starting and destination points may be expressed by means of dependencies:

$$K = \sum K_{i,k} \cdot d_k \quad (37)$$

where:

K – total cost of local distribution,
$K_{i,d}$ – cost of transport (transport to or from) of consignments on route k [Eur/km],
d_k – distance of k route,
n – number of routes.

In practice, the problem is more complicated, because the cost of driving of 1 km of the route is not fixed. It is directly related to the peculiarities of the route on which the ride is to take place, i.e. the quality of the infrastructure, location, accessibility, repeatedly also with the time of day. Even more complicated is the relationship between cost and distance. The task shall become additionally complex after taking into account the conditions required to meet the conditions indicating that the longer the route, the more consignments must be delivered during the journey. As a consequence of the conditions, it is necessary to increase the payload of the vehicle used for transport, which directly translates into the unit cost of delivery.

It would therefore be appropriate to take into account in the relationship analyses that the distance of the journey is determined by the payload of the van used and that the payload may be a function of the length of the route. Reasoning results from multithreaded relationships between function arguments, their effectiveness and impact.

When preparing a description of the criteria, it should be remembered that the efficiency of processes in local distribution depends on the size of the network, and the format of the network operation affects the distribution costs. It should also be borne in mind that the route selection algorithm being developed must be consistent and enable implementation in a functioning consignments distribution system.

After analysing the aspects of the issue discussed, it was concluded that it was appropriate to design the distribution system first and, at taking into account the forwarding structure, to undertake work on adapting the transport process. The efficiency of the implementation of processes, at the operational level, will depend on the structure of distribution built, which may prove to be a fundamental constraint during the implementation of the adaptation processes. In this case, adjustments will have to be made, e.g. in the functioning of the location system, the equipment of terminals, the payload of means of transport. The procedure results from the nature of the coupled relations between processes and levels of management.

5. Conclusions

The study was devoted to analysing multi-criteria decision-making methods with a view to using solutions in the process of developing methodologies for building customer relations in the field of transport services.

Literature broadly addressing the decision-making issues of MCDM multi-criteria has been reviewed and analysed. Research models and the use of decision-making processes used in each method to achieve the goal set in the work have been identified.

The practical use of multi-criteria methods in logistics and transport analyses has been verified. The strengths and weaknesses of the ways proposed in the work were presented. The solved and addressed research aspects have been reviewed and, within the transport area, examples of decision-making problems that use the specificities of specific methods have been reviewed. Methods such as ELECTE III, AHP, PROMETHEE I and UTA were selected to describe the specifics of the issues in logistics and transport.

For those selected, the issues of conduct and analytical procedures are discussed in detail. Examples discuss the practical use of multi-criteria methods to solve complex vehicle distribution tasks and aspects of vehicle use for local shipment distribution. The aim of the work was not to mark process parameters, but to combine the critical points of the solution in order to guarantee the stability and development of the processes resulting from the transport plan. The results confirmed the complexity of the issue of the productivisation of proceedings in complex transport systems.

It was found that using the total cost model, simulations of different combinations of direct and indirect services could be carried out, the costs of different transport variants could be calculated and a solution which meets the criterion of e.g. minimum costs could be chosen. Price, time and reliability, punctuality and flexibility are currently not the only elements of competition from transport companies. In order to achieve a high position in the market, it is necessary to combine supply chain management, customer relations and transport process. In the era of creating partnerships with customers, it is necessary to develop links with the systems of individual partners. It would be appropriate for the methods to be adaptable, i.e. to support information distribution processes in areas such as co-operators, suppliers, producers, distributors and customers. It is necessary to adapt to the needs of the final customer, who in a highly competitive consumer goods market can make a fully informed choice of products and services according to individual needs.

Optimization problems require the development of customized optimization models in each case. Although a single, holistic model describing the functioning of the whole system can be developed, there should be as many optimisation models as there are decision-making problems. Only in this case is it possible to distinguish the functions of the purpose and consider the different relationships of the analyzed processes.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-19-0444.

REFERENCES

[1] Dyer, J., Maut, Multiattribute Utility Theory, 2005.

[2] Roy B., Multi-criteria Decision Support,Scientific and Technical Publishing House, Warsaw, 1990.

[3] Roy B., Paradigms and challenges, 2005.

[4] Jahanshahloo G. R., Lotfi F.H., Izadikhah M., An Algorithmic Method to Extend TOPSIS for Decision-making Problems with Interval Data, "Applied Mathematics and Computation", 175, s. 1375-1384, 2006.

[5] Roszkowska E., Kacprzak D., The Fuzzy SAW and Fuzzy TOPSIS Procedures Based on Ordered Fuzzy Numbers, Information Sciences, 369, s. 564-584, 2016.

[6] Trzaskalik T., Multiple Criteria Decision Making (MCDM), Publishing House of the University of Economics in Katowice, 2006.

[7] Lotfi F. H., Fallahnejad R., Imprecise Shannon's Entropy and Multi Attribute Decision Making, Entropy, 12, s. 53-62, 2010.

[8] Kacprzak D., Objective Weights Based on Ordered Fuzzy Numbers for Fuzzy Multiple Criteria Decision Making Methods, Entropy, 19, s. 373, 2017.

[9] Kiksalan M., Wallenius J., Zionts S., Multiple Criteria Decision Making, From Early History to the 21st Century, World Scientific, New Jersey, London, Singapore, Beijing, Shanghai, Hong Kong, Taipei, Chennai, 2011.

[10] Banayoun R., Roy B., Sussman N., Electre Program Reference Manual, Synth Note and Formation 25. Scientific Directorate SEMA, (1966).

[11] Slamming T., Multi-criteria decision support. Methods and applications, EuP 2014.

[12] Zalewski W., Application of the TOPSIS method for assessing the financial condition of electricity distribution companies, Economics and Management4(4), 138-145, 2012.

[13] Szwabowski J., Rain J., Methods of multi-criteria comparative analysis, Silesian University of Technology Publishing House, Gliwice, 2001.

[14] Żabicki P., Gardziejczyk W., Selected aspects of multi-criteria analysis in roads design, Construction and Architecture, 13, 1, 2014, 213-222.

[15] Geneletti D., Multicriteria analysis to compare the impact of alternative road corridors: a case study in northern Italy, Impact Assessment and Project Appraisal, 23, 2, p. 135-146, 2005.

[16] Brauers W. K. M., Zavadskas E. K., Peldschus F., Turskis Z., Multi - objective decision - making for road design, Transport, 23, 3, 2008, 183-193.

[17] Afshari A., Mojahed M., Yusuff R., Simple Additive Weightingapproach to Personnel Selection problem, International Journal of Innovation, Management and Technology, 1, 5, p. 511-515, 2010.

[18] Vincke P., Multicriteria Decision-Aid, John Wiley & Sons, Chichester, 1992.

[19] Roy B., Multi-criteria Decision Support, Scientific Technical Publishing House, Warsaw, 1990.

[20] Keeney R., Raiffa H., Decision Analysis with Multiple Objectives. Preferences and Value Tradeoffs, Cambridge University Press, Cambridge, 1993.

[21] Żak J., Multi-criteria decision support in road transport, Poznań University of Technology, Poznan, 2005.

[22] Jacquet-Lagreze E., Siskos J., Assessing a Set of Additive Utility Functions for Multicriteria Decision-Making, the UTA Method, European journal of Operational Research, Vol. 10, s. 151-164, 1982.

[23] Siskos Y., Grigoroundis E., Matsatsinis F., UTA Methods. W: Figueira J., Greco S., Ehrgott M. (red.): Multiple Criteria Decision Analysis. State of the Art Surveys, Springer, New York, 2005.

[24] Saaty T., The Analytic Hierarchy Process, McGraw-Hill, New York, 1980.

[25] Saaty T., Transport Planning with Multiple Criteria: The Analitic Hierarchy Process Applications and Progress Review, Journal of Advanced Transportation, Vol. 29, Nr 1, s. 81-126, 1995.

[26] Figueira J., Greco S., Ehrgott M., Multiple Criteria Decision Analysis, State of the Art Surveys, Springer, New York, 2005.

[27] Roy B., The Outranking Approach and the Founddations of ELECTRE Methods. W: Bana-Costa C. (red.): Readings in Multiple Criteria Decision Aid, SpringerVerlag, Berlin, 1990.

[28] Roy B., ELECTRE III: A ranking algorithm based on a fuzzy representation of preferences in the presence of multiple criteria, Cahiers du Centre d'Etudes de Recherche Operationnelle, Vol. 20, Nr 1, s. 3-24, 1978.

[29] Roy B., Main Sources of Inaccurate Determination, Uncertainty and Imprecision in Decision Model. Mathematical and Computer Modeling, Vol. 12, Nr 10/11, s. 1245-1254, 1989.

[30] Roy B., Bertier P., La methode ELECTRE II - Une apllication au media-planning, Operational Research'72, North-Holland Publishing, Amsterdam, 1973.

[31] Roy B., Hugonnard J., Ranking of suburban line extension projects on the Paris metro system by a multicriteria method, Transportation Research, Vol. 16A, Nr 4, s. 301-312, 1982.

[32] Roy B., Present M., Silfol D., A programming method for determining which Paris metro stations should be renovated, European Journal of Operational Research, Vol. 24, s. 318-334, 1986.

[33] Roy B., Vanderpooten D., An Overview on "The European School of MCDA: Emergence, Basic Features and Current Works". European Journal of Operational Research, Vol. 99, Nr 1, s. 26-27, 1997.

[34] Roy B., Vanderpooten D., The European School of MCDA: A Historical Review. Journal of Multi-Criteria Decision Analysis, Vol.5, s. 22-38, 1996.

[35] Roy B., Vanderpooten D., The European School of MCDA: Emergence, Basic Features and Current Work, International Journal of Multi-Criteria Decision Analysis, Vol. 5, Nr 1, s. 22-36, 1996.

DOI: 10.26552/tac.C.2021.2.4

[36] Vincke P., Multicriteria Decision-Aid, John Wiley & Sons, Chichester, 1992.

[37] Brans J., Mareschal B., PROMETHEE Methods. W: Figueira J., Greco S., Ehrgott M. (red.): Multiple Criteria Decision Analysis. State of the Art Surveys, Springer, New York, 2005.

[38] Vuchic V. R., Urban Public Transportation Systems, Prentice-Hall, s. 673 1981.

[39] Vuchic V., Urban Transit: Operations, Planning and Economics. J. Wiley and Sons, New York, 2005.

[40] Brans J., Vincke P., A Preference Renking Organization Method, Management Science, Vol. 31, s. 647-656, 1985.

[41] Brans J., Mareschal B. i Vincke P., PROMETHEE: A New Family of Outranking Methods in Multicriteria Analysis. W: Brans J. (red.): Operational Research'84, Amsterdam, North-Holland Publishing, Amsterdam, s. 408-421, 1984.

[42] Brans J., Vincke P. i Mareschal B., How to Select and How to Rank Projects: The PROMETHEE Method. European Journal of Operational Research, Vol. 24, 1986, s. 228-238.

[43] Pastijn H., Leysen J., Constructing an Outranking Relation with OREST, Mathematical and Computer Modelling, Vol. 12, Nr 10/11, s. 576-587, 1989.

[44] Roubens M., Preference Relations on Actions and Criteria in Multicriteria Decision Making, European Journal of Operational Research, Vol. 10, s. 51-55, 1982.

[45] Greco S., A New PCCA Method: IDRA, European Journal of Operational Research, Vol. 98, Nr 3, s. 587-601, 1997.

[46] Matarazzo B., MAPPAC as a Compromise Between Outranking Methods and MAUT, European Journal of Operational Research, Vol. 54, Nr 1, s. 48-65, 1991.

[47] Matarazzo B., Preference Ranking Global Frequencies in Multicriterion Analysis (PRAGMA), European Journal of Operational Research, Vol. 36, Nr 1, s. 36-49, 1988.

[48] Greco S., Matarazzo B., Słowiński R., Multicriteria Classification by Dominance Based Rough Set Approach, Methodological Basis of the 4eMka System. W: Kloesgen W., Zytkow J. (red): Handbook of Data Mining and Knowlage Discowery, Oxford University Press, New York, 2002.

[49] Vuchic V. R., Urban Public Transportation Systems. Prentice-Hall, s. 673, 1981.

[50] Żak J., The Methodology of Multiple-Criteria Decision Making in the Optimization of an Urban Transportation System: Case Study of Poznan City in Poland, International Transactions in Operational Research, Vol. 6, Nr 3, s. 571-590, 1999.

[51] Vanderpooten D., The Use of Preference Information in Multiple Criteria Interactive Procedures, W: Locket A., Islei G. (red.): Improving Decision Making in Organizationa, Springer-Verlag, Berlin, 1989.

[52] Jaszkiewicz A., Słowiński R., The „Light Beam Search" Approach - an Overview of Methodology and Applications, European Journal of Operational Research, Vol. 113, Nr 2, s. 300-314, 1999.

[53] Jaszkiewicz A., Słowiński R., The LBS - Discrete Interactive Procedure for Multiple-Criteria Analysis of Decision Problems, W: Climaco J. (red.): Multicriteria Analysis. Proceedings of the 11th International Conference on MCDM, August 1-6, 1994, Coimbra, Springer-Verlag, Berlin-Heidelberg, s. 320-330, 1997.

[54] Jaszkiewicz A., Słowiński R., The Light beam Search - Outranking Based Interactive Procedure for Multiple-Objective Mathematical Programming, W: Pardalos P., Siskos Y. i Zopounidis C.: Advances in Multicriteria Analysis, Kluwer Academic Publishers, Dordrecht, 1995.

[55] Korhonen P., Wallenius J., A Modification of the Zionts-Wallenius Maltiple Criteria Method for Nonlinear Utility Functions, Helsinki School of Economics Press, Helsinki, 1985.

[56] Wierzbicki A., The Use of Reference Objectives in Multi-objective Optimization, (red.): Fandel G., Gal T.: Multiple Criteria Decision Making. Theory and Applications. Lecture Notes in Economics and Mathematical Systems, Springer-Verlag, Berlin, Vol. 177, 1980.

[57] Korhonen P., Wallenius J., A Modification of the Zionts-Wallenius Maltiple Criteria Method for Nonlinear Utility Functions, Helsinki School of Economics Press, Helsinki, 1985.

[58] Żak J., Fierek S., Desing and Evaluation of Alternative Solutions for an Integrated Urban Transportation System, Proceedings of the World Conference on Transport Research, Berkeley 2007.

[59] Churchman C.W., Ackoff R.L., An approximate measure of value, Journal of Operations Research Society of America, 2, 1, 172-187, 1954.

[60] Afshari A., Mojahed M., Yusuff R., Simple Additive Weightingapproach to Personnel Selection problem, International Journal of Innovation, Management and Technology, 1, 5, 511-515, 2010.

[61] Tzeng G. H., Huang J. J., Multiple Attribute Decision Making. Methods and Applications, CRC Press, London, 2011.

[62] Lootsma F.A., The REMBRANDT system for multi-criteria decision analysis via pairwise comparisons or direct rating, Report 92-05, Faculty of Technical Mathematics and Informatics, Delft University of Technology, Delft 1992.

[63] Saaty T. L., Decision making with dependence and feedback, The analytic network process. RWS Publications, 4922 Ellsworth Ave., Pittsburgh, 1996.

[64] Mikhailov, L., Tzvetinov P., Evaluation of services using a fuzzy analytic hierarchy proces, Applied Soft Computing Journal", 5, p. 23-33, 2004.

[65] Larichev O. I., Moskovich H. M., ZAPROS-LM - a method and system for ordering multiattribute alternatives, European Journal of Operational Research, 82(3), p. 503-521, 1995.

[66] Larichev O., Ranking multicriteria alternatives: The method ZAPROS III, European Journal of Operational Research, 131, p. 550-558, 2001.

[67] Konarzewska-Gubała E., Bipolar: Multiple Criteria Decision Aid Using Bipolar Refernce System, LAMSADE, Cashier et Documents, 56, 2009.

[68] Roy B., Vincke P., Relational Systems of Preference with One or More Pseudo-Criteria: Some New Concepts and Results, Management Science, Vol. 30, Nr 11, s. 1323-1335, 1984.

[69] Roy B., Bouyssou D., Aide Multicritere a la Decision: Methods at Cas, Economica. Paris 1993.

[70] Zaraś K., Martel J. M., Multiattribute Analysis Based on Stochastic Dominance, [in:] B. Munier B., Machina M. J. (eds.): Models and Experiments in Risk and Rationality, Kluwer Academic Publishers, Dordrecht 1994.

[71] Brans J., Vincke P., A Preference Renking Organization Method, Management Science, Vol. 31, s. 647-656, 1985.

[72] Brans J.P., L'ingenierie de la decision; Development of decision-support instruments. La methode PROMETHEE, [in:] Nadeau R., Landry M. (eds.): L'aide a la decision: Nature, Instruments et Perspectives d'Avenir, Presses de l'Universite Laval, Quebec 1982.

[73] Górecka D., Muszyńska J., Spatial analysis of innovation of Polish regions, Acta Universitatis Lodziensis Folia Oeconomica, Publishing House of the University of Lodz, p. 55-70, 2011.

[74] Diakoulaki D., Koumoutsos N., Cardinal ranking of alternative actions: extension of the PROMETHEE method, European Journal of Operational Research, 53, 1991.

[75] Górecka D., Szałucka M., Country market selection in international expansion using multicriteria decision aiding methods, Multiple Criteria Decision Making", 8, p. 31-55, 2013.

[76] Nowak M., Investment project evaluation by simulation and multiple criteria decision aiding procedure, Journal of Civil Engineering and Management, 11, p. 193-202, 2005.

[77] Górecka D., Application of multi-criteria methods basedon superiority relationships for the evaluation of European investment projects, Publishing House of the University of Economics in Katowice, Katowice 2010.

[78] Jahanshahloo G. R., Hosseinzadeh Lotfi F., Izadikhah M., Extension of the TOPSIS method for decision-making problems with fuzzy data, Applied Mathematics and Computation 185, p. 1544-1551, 2007.

[79] Opricovic S. Tzeng G. H., Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, European Journal of Operational Research", 156 (2), p. 445-455, 2004.

[80] Gabus A, Fontela E., Perceptions of the world problematic: Communication procedure, communicating with those bearing collective responsibility, DEMATEL 1. Battelle Geneva Research Centre, Geneva 1973.

[81] Buchanan J., Sheppord P., Ranking Projects Using the ELECTRE Method, Proceedings of the 33rd Annual Conference of Operational Research Society of New Zealand, Aucland, 1998.

[82] Beria P., Maltese I. i Mariotti I., Multicriteria versus Cost Benefit Analysis: a comparative perspective in the assessment of sustainable mobility, European Transport Research, Vol. 4, s. 137-152, 2012.

[83] Trzaskalik T., Sitarz S., Dominiak C., Unified procedure for Bipolar method, [in:] Zadnik L., Žerovnik J., Poch. J., Drobne S., Lisec A. (eds.): SOR'13 Proceedings 2013.

[84] Beder S., Costing the Earth: Equity, sustainable development and environmental economics, New Zealand Journal of Environmental Law, Nr 4, s. 227-243, 2000.

[85] Bonsall P., Borken J., Are We Moving in the Right Direction? Transport's Environmental Impact Assessment with ELECTRE III. W: Jaszkiewicz A. (red.): Advanced OR and AI Methods in Transportation, Poznań, 2005, s. 166-171.

[86] Nowak M., Interactive multi-criteria decision support under risk conditions, Methods and applications. Publishing House of the Academy of Economics in Katowice, Katowice 2008.

[87] Nowak M., Trade-off analysis in discrete decision making problems under risk, [in:] Lecture Notes in Economics and Mathematical Systems 638, [in:] Jones D., Tamiz M., Ries J. (eds.): New Developments in Multiple Objective and Goal Programming, Springer Verlag, p. 103-115, 2010.

[88] Malczewski J., Moreno-Sanchez R., Bojorquez-Tapia L., Ongay-Delhumeau E., Multicriteria Grup Decision - Making for Environmental Conflict Analysis in the Cape Region, Mexico, Journal of Environmental Planning and Management, Vol. 40, Nr 2-3, s. 175-1891992.

[89] Ngai E., Selection of Web Sites for Online Advertising Using AHP, Information of Management, Vol40(4), p.233-242,2003.

[90] Hafeez K., Zhang Y. i Malak N., Determining Key Capabilities of a Firm Using Analytic Hierarchy Process, International Journal of Production Economics, Vol. 76, Nr 1, s. 39-51, 2002.

[91] Olson D. L., Comparison of three multicriteria methods to predict known outcomes, European Journal of Operational Research, Vol. 130, Nr 3, s. 576-587, 2001.

[92] Hababou M., Martel J., A multicriteria approach for selecting a portfolio manager, INFOR, Vol. 36, Nr 3, s. 161-176, 1998.

[93] Spyridakos A., Multicriteria job evaluation for large organisations, European Journal of Operational Research, Vol. 130, Nr 2, s. 375-387, 2000.

[94] Geldermann J., Spengler T., Rentz O., Fuzzy outranking for environmental assessment, Case study: iron and steel making industry. Fuzzy Sets and Systems, Vol. 115, Nr 1, s. 45-65, 2001.

[95] Korpela J., An analytic approach to production capacity allocation and supply chain desing, International Journal of Production Economics, Vol. 78, Nr 2, s. 187-195, 2002.

[96] Żak J., Fierek S., Żmuda-Trzebiatowski P., Kruszyński M.: Multiple Level, Multiple Criteria Ranking Transportation Project, Proceedings of the 13th World Conference on Transport Research, Rio de Janeiro, 2013.

[97] Żak J., Thiel T., Multiple Criteria Evaluation of the Development Scenarios of the Mass Transit System, W: Park C-H., Oh J., Hayashi Y., Viegas J. (red.): CD Selected, Proceedings of the 9th World Conference on Transport Research, Seoul, 2001.

[98] Żak J., Fierek S., Kruszyński M., Evaluation of different transportation solutions with the application of Macro Simulation tools and Multiple Criteria Group Decision Making/Aiding methodology, Proceedings of the 16th Meeting of the EURO Working Group of Transportation, Porto, 2013.

[99] Żak J., The MCDA Methodology Applied to Solve Complex Transportation Decision Problems, Proceedings of the 9th Meeting of the EURO Working Group on Transportation: Intermodality, Sustainbility and Inteligent Transportation Systems, s, 685-693, Bari 2002.

[100] Dulmino R., Minnino V., Supplier Selection Using a Multi-Criteria Decision Aid Method, Journal of Purchasing & Supply Management, Vol. 9, Nr 4, s. 177-187, 2003.

ISSN: 1339-5130
DOI: 10.26552/tac.C.2021.2.4

[101] Radojevic D., Petrovic S., A Fuzzy Approach to Preference Structure in Multicriteria Ranking, International Transaction in Operations Research, Vol. 4, Nr 5-6, s. 419-430,1997.

[102] Jacquet-Lagreze E., Meziani R., Słowiński R., MOLP with an Interactive Assessment of Piecewise-Linear Utility Function, European Journal of Operational Research, Vol. 31, Nr 3, s. 350-357, 1987.

[103] Żak J., Modeling and optimization of decision-making problems in transport and forwarding companies. Use of multi-secretarial decision support methodology for modeling and optimization of decision-making problems in transport and forwarding companies,Institute of Logisticsand Warehousing, Poznań, 1999-2001.

[104] Sawicka H., Method of reorganization of the goods distribution system, Doctoral dissertation. Warsaw University of Technology, Faculty of Transport, Warsaw, 2012.

[105] Bradley S., Hax A., Magnanti T., Applied Mathematical Programming, Addison-Wesley Publishing, San Francisco, 1977.

[106] Jacyna M., Turkowski D., Selected aspects of the multi-criteria assessment of the selection of means of transport in vehicle distribution systems, Logistics4/2014.

[107] Milewski D., Optimization problems in the transport of small shipments, ScientificNotebooks of Szczecin University, No. 644, Transport and Logistics Problems No. 14/2011.

TRANSPORT AND COMMUNICATIONS

Scientific journal intended to combine theory and practice in the field transport and communications and thus advancement of transport and communications sciences.

Each paper was reviewed by two reviewers. Authors hold responsibility for linguistic quality (language as well as grammar accuracy) of the article.

The Scope of Journal: Transport and postal policy, Public passenger transportation systems, Quality of transport and post services, Demand and supply in transport, post and telecommunications, Logistic systems, Road transport, Rail transport, Water transport, Air transport, The business environment in the SR, The cross-border cooperation.

Journal is excerpted in **Index Copernicus** database (ICV 2020 83.22).

Frequency of publishing: Twice per year.

Publishing language:	English
Publisher:	The Faculty of Operation and Economics of Transport and Communications, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia
Printed:	EDIS – Printing House of the University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia
IČO	00 397 563
Edition:	20 pc
Registered No:	EV 4902/13
Tel:	++421/41/5133051
Email:	tac@fpedas.uniza.sk
Web:	https://tac.uniza.sk

November 2021

DOI: 10.26552/tac.J.2021.2

ISSN 1339-5130

ISSN 1339-5130

DOI: 10.26552/tac.J.2021.2