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EVALUATION OF ENERGY-CONSUMPTION IN THE VEHICLES OF EU INTERNATIONAL COMMUNICATION INFRASTRUCTURE

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Summary. In the present work an evaluation is carried out of a vehicle's energy-consumption in the range of kinetic energy depending on speed profile implementation of disperse phase, acceleration and braking (retarded motion). The analysis included the vehicles' driving speed profiles on motorways in Germany, France and Spain. Variable statistic parameter calculations and indicator of distribution probability (WPR) were used for the analyses..

Key words: transportation logistics, vehicle's energy-consumption, kinetic energy loss, distribution of driving speed, statistic parameters, indicator of distribution probability.

INTRODUCTION

Analyses of energy-consumption were made basing on complex traffic tests [Siłka 1995; 1997; Sovran and other. 1981; Staska 1984]. For operation conditions of transport facilities there is, however, deficiency of energy-consuming evaluations basing on calculus of probability caused by an influence of different traffic infrastructure factors and different driving techniques, which always determine a random process.

Car motion is characterized by continuous speed variations. Frequency, range and intensity of these variations depend on the external factors, vehicle properties but also the driver's behaviour. The external factors include: road properties, especially hills and other resistance-causing obstacles, road traffic conditions and weather conditions. The previous analyses [Siłka 1998] did not involve the driver's reactions and external conditions, but only constant influence of driving gear efficiency, loads, drive resistances etc.

In specified traffic conditions, mainly on out of city roads, in implemented profile of traffic, the driver has a higher possibility of easier way for the speed variations, while in city traffic generally, particular phases are short and separated with stoppage periods. Because of that there is a need of solution exploration leading to traffic optimization, to receive minimal traffic energy consumption simultaneously with the lowest losses of energy processing and transmission [Siłka 1997; Siłka and other 1995; Sovran and other 1981].

In the previous test analyses were to specify how fuel usage depends on its speed profile in one drive circle and what is the influence of an engine's properties and the vehicle itself [Januła and other 1989 ; Siłka 1997;1998].

PURPOSE OF THE THESIS

The purpose of the following thesis is to try and separate energy losses caused by driver's reaction and surroundings (effective driving conditions) from the complete vehicle's energy consumption. The calculations were made on the basis of motorway traffic agglomeration.

THEORETICAL BASIS OF A WEHICLE'S ENERGY CONSUMPTION ACCORDING TO THE PROFILE OF DRIVING SPEED

Traffic energy-consumption is a basic element of a car's energetic balance in which an essential part are energy losses. They determine considerable percentage of total energy delivered in the fuel. Depending on the accomplished speed profile, traffic energy consumption can change in a wide range of values. Through energy losses, traffic energy-consumption as an element of energy balance, has a determining influence on fuel usage during driving with various speeds. Traffic energy consumption is equal to energy expenditure for traffic drags and for inertia force overcome during acceleration [Dębicki 1974; Siłka 1990; 1994;1997;1998].

Traffic energy consumption elements which are the subject of the present analysis can be formulated in time function with equations:

$$E_t = mg\, f_t \int_0^{T_n} v\,dt, \tag{1}$$

$$E_p = c_x A \varepsilon \int_0^{T_n} v^3\,dt, \tag{2}$$

$$E_k = m \int_0^{T_a} av\,dt, \tag{3}$$

where: Tn, Ta – adequate driving time in propel and acceleration phase [Siłka 1993].

Coasting and braking phase influence is formulated with the above-received kinetic energy cost (coasting) or with using brakes.

Momentary delay has the form:

$$\frac{dv}{dt} = \frac{Fop}{m}, \tag{4}$$

where: Fop – summary traffic force resistance [N],
m – car weight [kg].

From the above formula it follows that time and coasting distance is equal to:

$$t_w = m \int_{Vp}^{Vk} \frac{dv}{F_{op}}, \tag{5}$$

$$s_w = m \int_{Vp}^{Vk} \frac{v\,dv}{F_{op}}. \tag{6}$$

While during appropriate braking i.e. with using brakes:

$$\frac{dv}{dt} = \frac{1}{m}\left[F_H(v) + F_{op}(v)\right], \tag{7}$$

where:
m – car weight [kg]; F_{op} – summary traffic force resistance [N];
F_H – braking force on wheels [N]; v – speed [m/s; km/h].
Hereof time and braking distance is equal to:

$$T_H = m\int_{V_p}^{Vk}\frac{dv}{F_H + F_{op}}, \tag{8}$$

$$L_H = m\int_{V_p}^{Vk}\frac{v dv}{F_H + F_{op}}. \tag{9}$$

Basing on analyses [Sovran and other 1981] it was found that distracted with brakes energy determines about 34% of total energy value delivery to power wheels. Hereof braking with using brakes as non-economical process in respect of energy, should be maximally limited.

SUBJECT AND RESEARCH OBJECT

The research subject was an analysis of driving speed profile of a truck (TIR) in conditions of communication infrastructure type motorway in EU (Germany, France, Spain).

RESEARCH METHOD

In accepted research method, vehicle traction parameters were analyzed basing on vehicle's tachographic recording (recording chart) on route Poland – Germany – France – Spain.

In respect of big amount of vehicle's traffic speed research results, profile analysis was limited to selected range of motorway routes with the lowest standard deviation (coefficient of variation). There were also taken to consideration different hours of day graph driving. Profiles of day driving speed concerned:

– Germany – two profiles of driving speed (time 22:00-24:00 and time 4:00-6:00) route Munchherg – Audeux;

– France – one profile of driving speed (time 12:00-14:00) route Audeux – Borhecieux;

– Spain – two profiles of driving speed (time 17:00-19:00, 24:00-2:00) route Venda da Bano – Ciavacia.

Reading of recording charts (profile of driving speed) was made in two ranges:

– maximal kinetic energy expenditure (upper peaks of profile – F1),

– energy expenditure losses as lower range of maximum received in result of casting and braking (F2).

RESEARCH RESULTS

Received results of speed distribution (v) statistical calculations of empirical variation F1 and F2 were presented as schedule (table 1-3). Results of cumulative distribution function value calculations F1 and F2 were presented in tables 4-6.

Table 1. Statistic variable parameters of driving speed profile on motorway (Germany)

Statistic parameters	Working time (time 22.00-24.00)		Working time (time 4.00-6.00)	
	Calculation of energy-consumption speed losses of vehicle (v)		Calculation of energy-consumption speed losses of vehicle (v)	
	max F1	min. F2	max F1	min. F2
arithmetic average	84,43	65,54	86,58	65
variation	25,39	23,53	4,77	115,47
Standard deviation	5,04	23,53	2,18	10,7
Median	85	73,85	86,25	77,8
Dominant	85	77,27	84,57	78,89
Coefficient of variation	5,97%	35,9%	2,52%	16,46%
Distribution skewness	-0,11	-1,1	0,9	-1,29

Table 2. Statistic variable parameters of driving speed profile on motorway (France)

Statistic parameters	Working time (time 12.00-14.00)	
	Calculation of energy-consumption speed losses of vehicle (v)	
	max F1	min. F2
arithmetic average	72,5	55,95
variation	240,5	575,46
Standard deviation	15,51	23,99
Median	153,75	131
Dominant	45	40
Coefficient of variation	21,39%	42,88%
Distribution skewness	1,77	0,66

Table 3. Statistic variable parameters of driving speed profile on motorway (Spain)

Statistic parameters	Working time (time 17.00-19.00)		Working time (time 24.00-2.00)	
	Calculation of energy-consumption speed losses of vehicle (v)		Calculation of energy-consumption speed losses of vehicle (v)	
	max F1	min. F2	max F1	min. F2
arithmetic average	83,18	72,77	80	65,51
variation	13,85	387,89	60,58	371,26
Standard deviation	3,7	19,69	7,78	19,26
Median	230	86,25	60	76,25
Dominant	55	80	62,22	52,5
Coefficient of variation	4,4%	27%	9,6%	29%

AN ANALYSIS OF RESEARCH RESULTS
EMPIRICAL DISTRIBUTION FUNCTION AND SID

An analysis of research results was presented based on calculation methods of statistic values and similarity indicator distributions (SID) of the analyzed variable (v) [Bochniak 2006; Burski 2008 a; Burski and other 2008 b], (values F1 and F2 of variable v) and cumulative bar chart of motorway frequency (empirical distribution function), (drawings 1-3).

Table 4. a, b. Results of cumulative distribution function calculations of distribution v (Germany, a – time 22:00-24:00; b – time 4:00-6:00).

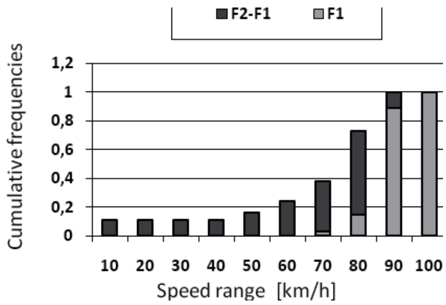
a)

v	F1	F2-F1	F2
10	0	0,108	0,108
20	0	0,108	0,108
30	0	0,108	0,108
40	0	0,108	0,108
50	0	0,162	0,162
60	0	0,243	0,243
70	0,028	0,35	0,378
80	0,142	0,587	0,729
90	0,885	0,115	1
100	1	0	0

b)

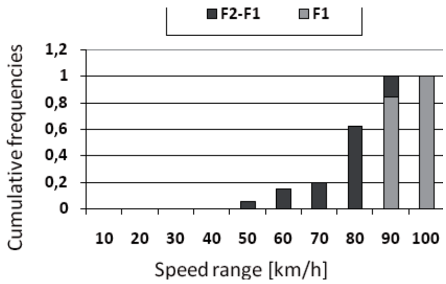
v	F1	F2-F1	F2
10	0	0	0
20	0	0	0
30	0	0	0
40	0	0	0
50	0	0,048	0,048
60	0	0,143	0,143
70	0	0,191	0,191
80	0	0,62	0,62
90	0,842	0,158	1
100	1	0	0

a)



Range F2-F1=1,16; Average of range 0,116

b)

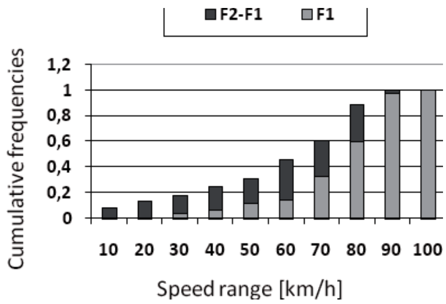


Range F2-F1 = 1,16; Average of range 0,116

Fig. 1. a, b. Graph of empirical distribution functions F1 and F2 and value of surface content between them (Germany, a – time 22:00-24:00; b – time 4:00-6:00).

Table 5. Results of cumulative distribution function calculations of distribution v (France time 12:00-14:00).

v	F1	F2-F1	F2
10	0	0,081	0,081
20	0	0,135	0,135
30	0,038	0,138	0,176
40	0,063	0,181	0,244
50	0,113	0,199	0,312
60	0,138	0,323	0,461
70	0,325	0,285	0,61
80	0,6	0,292	0,892
90	0,975	0,025	1
100	1	0	0



Range F1-F2 = 1,659; Average of range 0,1659

Fig. 2. Graph of empirical distribution functions F1 and F2 and value of surface content between them (France time 12:00-14:00)

Table 6. a, b. Results of cumulative distribution function calculations of distribution v (Spain, a – time 17:00-19: 00; b – time 24:00-2:00)

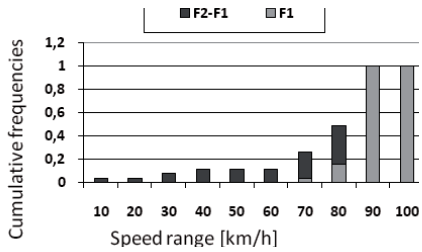
a)

v	F1	F2-F1	F2
10	0	0,037	0,037
20	0	0,037	0,037
30	0	0,074	0,074
40	0	0,111	0,111
50	0	0,111	0,111
60	0	0,111	0,111
70	0,03	0,229	0,259
80	0,151	0,33	0,481
90	1	0	1
100	1	0	0

b)

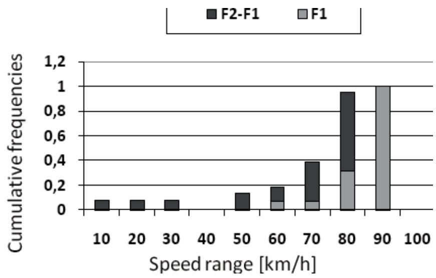
V	F1	F1-F2	F2
10	0	0,076	0,076
20	0	0,076	0,076
30	0	0,076	0,076
40	0	0,076	0,076
50	0	0,127	0,127
60	0,068	0,11	0,178
70	0,068	0,315	0,383
800	0,309	0,638	0,947
90	1	0	1
100	0	0	0

a)



Range F1-F2 = 1,04; Average of range 0,115556

b)



Range F1-F2 = 1,494; Average of range 0,166

Fig. 3. a, b. Graph of empirical distribution functions F1 and F2 and value of surface content between them (Spain, a – time 17:00-19: 00; b – time 24:00-2:00)

In the executed analysis of similarity research results of kinetic energy loss (SID), in conditions of motorway traffic the following relations were included: Germany – France, Germany – Spain, France – Spain. In comparison of the received values of ranges F1 – F2 for different distributions it was necessary to standard their values. In reference to value x dispersion of calculations, average value $\bar{X}$ was included (drawings 4-6). However in Tables (7.a-9.a) the results were presented of distance calculations of smaller points (D_-) and bigger points (D_+) to the average value ($\bar{X}$) and in Tables (7.b-9.b) there were calculated values SID min and SID max.

France $\bar{X}$	0,1659
Germany $\bar{X}$	0,116
Average (total)	0,14095

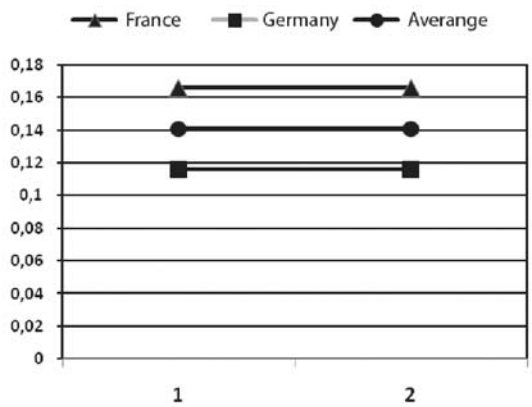


Fig. 4. Average values ($\bar{X}$) for particular distributions and their averaging (France – Germany)

Table 7. a, b. Results of calculations of smaller distances (D_-) and bigger distances (D_+) to the average value (a) and SID (b), (Germany – France)

a)

D_					
Average	x_i	$x_i - \overline{X}$	$(x_i - \overline{X})^2$	$\frac{(x_i - \overline{X})^2}{1}$	$\sqrt{\frac{(x_i - \overline{X})^2}{1}}$
0,14	0,116	-0,024	0,000576	0,000576	0,024
D_+					
0,153	0,1659	0,0259	0,000671	0,000671	0,0259

b)

D_-+D_+	Pu	Pu^2	SID min	SID max
0,0499	0,282465	0,079786	0,717535	0,920214

Germany $\overline{X}$	0,116
Spain $\overline{X}$	0,140778
Average (total)	0,128

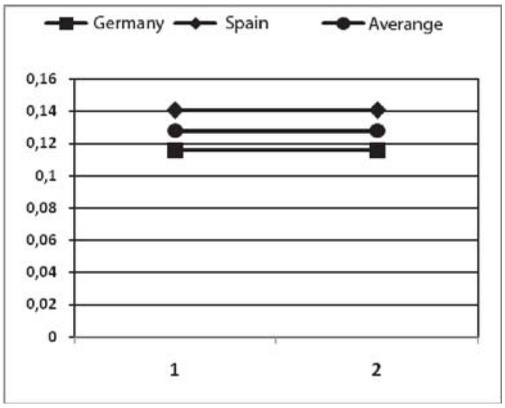


Fig. 5. Average values ($\overline{X}$) for particular distributions and their averaging (Germany – Spain)

Table 8. a, b. Results of calculations of smaller distances (D_-) and bigger distances (D_+) to the average value (a) and SID (b), (Germany – Spain)

a)

D_					
Average	x_i	$x_i - \overline{X}$	$(x_i - \overline{X})^2$	$\frac{(x_i - \overline{X})^2}{1}$	$\sqrt{\frac{(x_i - \overline{X})^2}{1}}$
0,128	0,116	-0,012	0,000144	0,000144	0,012
D_+					
0,153	0,140778	0,012778	0,000163	0,000163	0,0127

b)

D_-+D_+	Pu	Pu^2	SID min	SID max
0,0247	0,051979	0,002702	0,948021	0,997298

France $\bar{X}$	0,1659
Spain $\bar{X}$	0,140778
Average (total)	0,153

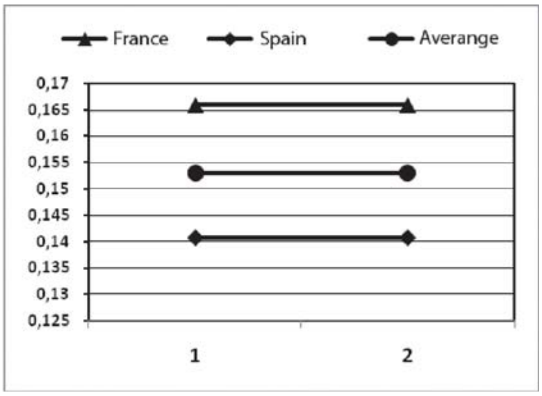


Fig. 6. Average values ($\bar{X}$) for particular distributions and their averaging (France -Spain)

Table 9. a, b. Results of calculations of smaller distances (D_-) and bigger distances (D_+) to the average value (a) and SID (b), (France – Spain)

a)

D_					
Average	x_i	$x_i - \bar{X}$	$(x_i - \bar{X})^2$	$\frac{(x_i - \bar{X})^2}{1}$	$\sqrt{\frac{(x_i - \bar{X})^2}{1}}$
0,153	0,140778	-0,01222	0,000149	0,000149	0,0122
D_+					
0,153	0,1659	0,0129	0,000166	0,000166	0,01288

b)

D_-+D_+	Pu	Pu^2	SID min	SID max
0,02508	0,583333	0,340278	0,416667	0,659722

Table 10. Scale of distributions similarity (SID)

Indicator value	Scale of distributions similarity
(9,0;1⟩	Very similar
(0,7;0,9⟩	similar
(0,5;0,7⟩	Little similar
(0,3;0,5⟩	Very little similar
(0,1;0,3⟩	Dissimilar
⟨0;0,1⟩	Very dissimilar

CONCLUSIONS

As a result of the executed statistical analyses of empirical variation distribution the following particular conclusions were obtained:

1. Standard deviation as classic measurement of variation in case of German motorway shows much lower concentration of traffic profile values during a vehicle's morning driving (4:00-6:00). A similar value is shown by standard deviation of driving on a motorway in France or Spain (irrespective of driving time).

2. In case of coefficient of variation describing dispersion relation (standard deviation) to average value, there are two relevant differences between day driving distributions. F. e. on a motorway in Germany in the evening (22:00-24:00) the distribution value is two times higher than in the morning (4:00-6:00). While traffic conditions include different phases, there are no bigger differences in case of Spain.

The calculated distribution skewness in case of a German motorway equal to -0,11 shows that the distribution is characterized by left-sided symmetry, while on a French motorway it is included between 0,66 and 1,77 depending on an analysed range of speed profile.

An analysis of similarity indicator distribution (SID), describing kinetic energy losses showed:

1. In range of distribution similarity of functions Germany – France, that the minimal value of SID (0,717) according to Table 7 is found for distribution similarity and the maximal SID value (0,92) has a very similar distribution.

2. In range of similarity (Germany – Spain) both SID min (0,948) and SID max (0,997) show very similar surface kinetic energy losses.

3. In range of driving speed profile energy losses in relation Spain – France, the value of SID min = 0,416 describing dissimilarity of those losses, while SID max (0,659) confirms it as not similar. Profile of driving on motorways in EU shows that in parallel communication infrastructure different driving conditions can occur which has an influence on kinetic energy losses. In view of the above, standardization research should be continued.

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OCENA ENERGOCHŁONNOŚCI POJAZDU W MIĘDZYNARODOWEJ INFRASTRUKTURZE KOMUNIKACYJNEJ UE

Streszczenie. W pracy przedstawiono ocenę energochłonności pojazdu w zakresie energii kinetycznej zależnej od realizowanego profilu prędkości fazy rozpędzania i przyśpieszania oraz hamowania (ruchu opóźnionego). Badaniom poddano przebiegi profilu prędkości jazdy pojazdu po autostradach Niemiec, Francji i Hiszpanii. W analizie wykorzystano obliczenia parametrów statystycznych zmiennych oraz wskaźnika podobieństwa rozkładów (WPR).

Słowa kluczowe: logistyka transportowa, energochłonność pojazdu, energia kinetyczna strat, rozkład prędkości jazdy, parametry statystyczne, wskaźnik podobieństwa rozkładu.