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Verification of energy consumption modelling in a vehicle under operating conditions of a transport company

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Summary. This paper presents the results of operating a car in the variable national and international infrastructure. The research aimed to evaluate the implementation of the AETR Act and the impact of infrastructure and vehicle loading capacity on fuel consumption (both the conventional and dissipated energy). In the calculations mathematical formalism of the adopted structural model was applied.

Key words: transport logistics, communication infrastructure, structural modeling, operational factors, fuel consumption, digital recording.

INTRODUCTION

The increasing globalization of the world economy requires a search by car transport companies of more efficient methods of their business. They allow for gaining competitive advantage in the international division of freight and distribution services [9,14,15].

As more countries achieve the advanced economic development, or even reach an emergency crisis [16], more and more commonly cars are equipped with different electronic telemetry devices to record their location, operational course or the current exchange of logistic information [4.10]. The range of such technical equipment includes, among others, the GTS systems, automatic vehicle control systems, speed limiters, electronic record of operating parameters (tachographs). In the future they are intended to become elements of the „black box" in a vehicle [4,6].

The ultimate goal of any business is profit [12]. The efforts aim, therefore, at the achievement of successful economic balance, after incurring undoubtedly large costs, and in some cases also addition of legally compulsory additional equipment [14.17].

Key features and benefits of transport logistics as a scientific field have been recognized in developed countries and successfully implemented. This purpose is served by research into vehicle kinetic energy, its efficient use and losses within different infrastructure, or influence of the flow of traffic on transport engineering [1, 2, 3, 18, 19, 20].

The purpose of this study is to analyze the course of operation of a vehicle in the selected shipping company providing domestic and international transport services. Specifically, in terms of the observation of AETR Act, vehicle kinetic energy expenditure, the losses depending on the speed, infrastructure and capacity. The analysis was based on the record of a digital tachograph type Stoneridge Electronics, in conjunction with the authors' previous studies on the structural modeling of kinetic energy losses in vehicles [4,5].

THE RESEARCH METHODOLOGY

The adopted research methodology involved the truck MAN TGL 12.180, dated from 2007, as the object of studies.

The technical data of the vehicle:
- Weight: 5890 kg,
- Maximum permissible mass: 11990 kg,
- The largest allowable axle load: 82.32 kN,
- Engine capacity: 4580 cm
- Engine power: 1322 kW (180 hp),
- 6-speed manual gearbox.

The analysis was performed of the record from ***Stoneridge Electronics*** digital tachograph, model SE 5000.

The technical data of the measuring device:
- Operating temperature from -25 ^{0}C to 70 ^{0}C,
- Certification and approval for use in accordance with the EU - ITSEC 'level E3 - high ", No of approval: e5 - 0.02;

– Electromagnetic compatibility according to the EU Commission Directive 95/54/EC.

Prior to research the tachograf had been secured by authorized personnel, and during the implementation of studies, there was no manipulation or modification of the equipment or the speed sensor [13].

RESULTS AND ANALYSIS

The results of the reading of *Stoneridge Electronics* tachograph's record of a vehicle in domestic freight are presented in Table (1), whereas in the international one – in Table (2).

Route I. Biłgoraj - Belzec - Cieszyn,
Route II. Mielec - Belzec - Bilgoraj,
Route III. Bilgoraj - Przeworsk - Bilgoraj,
Route IV. Kolbuszowa - Przeworsk - Belzec - Bilgoraj - Przeworsk - Machowa,
Route V. Machowa - Tarnow - Mielec - Tarnobrzeg

Route A - Cieszyn - Cadca (SK) - Mielec,
Route B - Bilgoraj - Mielec - Tarnow - Martin (SK)
Route C - Martin (SK) - Cadca (SK) - Cieszyn.

The analyses of the digital tachograph printouts in domestic freight (Table 1) and international freight (Table 2) showed that the drivers had complied with the applicable regulations concerning the working time (according to AETR). Only in two cases the digital recording suggested the exceeding of the total time of the driver's work, however, according to Art. 15, Act of April 16, 2004 on the working time of drivers, the cases must be considered acceptable (Journal of Laws No. 92, item. 879).

The obtained digital recording operating data (Table 1 and Table. 2) showed that, e.g.:
– with a similar driving time on the national road (0,5.0.5) and (10.05) and international one (04.05), there occurred differences in the length of route,
– on international routes of similar length (05.05 and 11.05) there were significant differences in the length of driving time,
– on similar routes (5-6.05), at the existing driving conditions, a highly loaded vehicle (Table 3) could cover the distance faster then a vehicle without load.

The mathematical formalism of probability distribution of driving speed oscillogram amplitudes in the existing communication infrastructure is presented in the form of an empirical relationship (formula 1÷3):

$$y_1 = -0,0393x^5+1,0342x^4-9,7313x^3+40,35x^2-71,889x+42,842$$
$$R^2 = 0,7768$$

$$y_2 = -0,0358x^5+0,9635x^4-9,333x^3+39,863x^2-71,719x+43,617 \qquad (1÷3)$$
$$R^2 = 0,8741$$

Table 1. The results of the reading of *Stoneridge Electronics* tachograph's record of a vehicle in domestic freight

No	Description of daily activities	Travel date (Route No I - V)				
		04.05.11/I	**06.05.11/II**	**09.05.11/III**	**12.05.11/IV**	**13.05.11/V**
1.	Driving the vehicle	8 h 33 min.	4 h 07 min.	5 h 36 min.	8 h 02 min.	3 h 0 min.
2.	Other work	27 min.	1 h 22 min.	1 h 15 min.	1 h 25 min.	59 min.
3.	Rest	15 h	9 h 50 min.	17 h 09 min.	14 h 33 min.	8 h 08 min.
4.	Distance covered	513 km	220 km	286 km	405 km	129 km
5.	Average speed	60 km/h	53 km/h	51 km/h	50 km/h	43 km/h
6.	Total run time	9 h	5 h 25 min.	6 h 51 min.	9 h 27 min.	3 h 59 min.

Table 2. The results of the reading of *Stoneridge Electronics* tachograph's record of a vehicle in international freight

No	Description of daily activities	Travel date (Route No VI - VII)		
		05.05.11/A	**10.05.11/B**	**11.05.11/C**
1.	Driving the vehicle	8 h 20 min.	8 h 47 min.	7 h 55min.
2.	Other work	1 h 56 min.	1 h 17 min.	2 h 55 min.
3.	Rest	13 h 44 min.	13 h 54 min.	13 h 10 min.
4.	Distance covered	428 km	453 km	432 km
5.	Average speed	51 km/h	52 km/h	55 km/h
6.	Total run time	10 h 14 min.	10 h 04 min.	6 h 51 min.
7.	Time of the driver's availability	-	2 min.	-

Table 3. The results of measuring fuel consumption for variable loading capacity, considering average speed

No	Type of route by date of travel	Fuel consumption in l/100 km	Loading capacity of the vehicle 100% load in% of route	Loading capacity of the vehicle 50 % load in% of route	Without load 50 % load in% of route	Average speed of travel km/h
1.	5-6.05.2011	20,34 17,34	86,0 14,4	- 24,9	14,0 60,7	59,5 52,9
2.	9-13.05.2011	16,79 18,37 17,20	24,0 55,4 29,8	76,0 - 53,6	- 44,6 16,6	50,5 52,4 49,2

Table 4. The results of measurements of fuel consumption in variable transport infrastructure at average speed

No	Type of route by date of travel	Fuel consumption l/100 km	Type of communication infrastructure in the whole route, %			
			Freeways	European ways	Local ways	Average speed km/h
1.	5-6.05.2011	20,34 17.37	- 13,8	70,6 50,9	29,4 35,3	59,5 52,9
2.	9-13.05.2011	16,79 18,37 17,20	- 7,4 -	7,5 39,4 33,1	92,5 53,2 66,9	50,5 52,4 49,2

$y_3 = 0,0086x^5 - 0,2391x^4 + 2,2732x^3 - 8,504x^2 + 12,311x - 1,0867$

$R^2 = 0,7395,$

where:

y1 (international road), y2 (expressway), y3 (national road) – level of amplitude probability distribution [%]);

x – speed interval [km / h].

This is the result of frequent modernization and repair of roads, lower standards of part of the route and, consequently, their lower speed limits as well as variable number of users [7].

Mathematical formalism of the adopted fuel consumption model taking into account the conditions of traffic infrastructure flow and utilization of the vehicle capacity is presented by the following relationship:

Gpg 1-3 = Aa + Bb + Cc + xex + Yan + Zwo, (4)

where:

$Gp_{g\ 1\text{-}3}$ - global (operational) fuel consumption [1/100 km],

A, B, C - the percentage of capacity on a route,

a, b, c - coefficients of the fuel consumption relative to loading capacity (0.29, 0.14, 0.07),

X, Y, Z-percent share of the infrastructure along the route,

ex,an,wo – traffic flow rates of high speed road, international (highway) road, provincial (voivodship) road (35.0, 13.4, 43.7).

It follows that:

Gp_g Gp_s = - (Aa + Bb + Cc + xex + Yan + Zwo (5)

where:

Gp_s - loss of fuel related to operational load capacity of a vehicle (Gp_l) and traffic flow (Gp_p),

Gp_g - global fuel consumption en route.

A more detailed analysis of fuel consumption, based on the calculated coefficients of the used load capacity of vehicles (WWT), in different communication infrastructure (at approximate average speeds) shows the corresponding fuel consumption - GP (expression 6÷8):

$$Gp_{g1} = 24.0a + 76.0b,$$
$$Gp_{g2} = 55.4a + 44.6c,$$
$$Gp_{g3} = 29.8a + 53.6b + 16.6c, \quad (6 \div 8)$$

where:

$Gp_{g1} \div Gp_{g2} = 16,79 \div 18,37;$

$a = 0,29,$

$b = 0,14,$

$c = 0,07.$

On the 05-06.05.2011 (Table 3) with 100% load at 86% of vehicle route and at 14% without load, the fuel consumption was 4.54 l, with the total consumption of 20-34 l / 100 km.

On the 09-13.05.2011 (Table 3) the loading capacity utilization causes such results as:

– when driving a vehicle loaded 50% over 24% of the route and 50% over 76% of routes per share of 92.5% of the provincial (voivodship) road, the fuel consumption associated with the vehicle loading is 6.94 l;

– For example, by driving the entire route with 100% utilization of load capacity, the vehicle would burn 26.1 l, with 50% capacity used - 6,30 l (at 7.4% of the high speed way and 39.4% international road as well as 53.2% of the provincial (voivodship) road);
– When driving on the route with 100% capacity used in its middle (55.4%) and in the second part (44.6%) - without load, the fuel consumption for this transport amounted to 6.6 l;
– When driving on the road with the participation of 29.8% - 100% load, 53.6% with 50% load and 16.6% without load, at 33.1% share of international road and 66% provincial road, the fuel consumption associated with the transport of cargo amounted to 5.86 l.

Dependencies (1÷2) represent the amplitude probability distributions taken as typical for the occurring in the studies traffic flow infrastructure [6]. On their basis, and on the basis of the distributed energy rates applicable for the infrastructure (WRE), an attempt was made to estimate the total value for the acceleration and deceleration phase of the vehicle speed. And so, in the case international (highway) road, WRE is 13.4%, in case of high speed way 35.0%, and for the provincial (voivodship) - 43.7% (expression 1÷3).

The analysis of the estimated loss of kinetic energy associated with the traffic flow of vehicles shows that:

a) on the 04 - 06/05/2011 (Table 4) - over 70.6% of the international road, the kinetic energy dissipation associated with the acceleration and deceleration phase of a vehicle speed was 1.92 l, and for driving on the provincial road (29.4% of the route) - 2.61 l (at the consumption of 20.34 l/100 km) which amounted to the total of 4.53 l;

b) on the 09-13.05.2011 (Table 4) – over 92.5% of the provincial road, the loss of dissipated fuel was 6.94 liters, at 16.79 l/100 km overall fuel consumption, in the case of participation of three types of communication infrastructure, with over 50% share of provincial road, the total loss amounted to 6.61 l at 18.37 l/100 km consumption, in the case of 31.1% share of international (highway) road and 66.9% of provincial road the total kinetic energy loss amounted to 5.78 l, at the consumption of 17.1 l/100 km.

The figures (estimates) based on field tests of the vehicle and the above-presented expressions point out at the possibility of a wider scientific analysis of energy consumption in transport infrastructure [18,19]. This is important in optimizing fleet management and operation of a transport company at international and national levels. Further studies support the theory that probability analyses, performance indicators from computer simulation models developing subsequent traffic flows, the related fuel consumption and statistical significance tests of the processes involved, will guarantee reliable results despite the random nature of the operational processes occurring here [8.11].

CONCLUSIONS

From the research carried out and attempt at a detailed analysis of the occurring operational dependencies in the national and international transport logistics the following conclusions of general character can be drawn:
– a digital record of a vehicle operation is a documented, important source of information not only for administrative control and law enforcement authorities, but due to its additional features and software is becoming an indispensable tool for scientific analysis serving to optimize the vehicle's work;
– progressive "digitalization" of a vehicle is particularly important in modeling operational processes, especially in research on intensity of energy consumption, resulting from a deepening energy crisis of conventional fuels;
– even with the wide participation of the existing global telemetry systems it is possible to obtain the necessary information with other methods (e.g. analysis of statistical significance of the processes) to optimize the management of fleet transport company. They have to be developed in order to increase its competitiveness in the proper selection of routes, loading capacity and reduction in fuel consumption. A special role here is played by a logistics specialist and a legislative adviser in enterprise management, familiar with the principles of their abstract (model) and systematic utilization [12].

REFERENCES

1. **Burski Z., Mijalska-Szewczak I. 2008.** Ocena energochłonności pojazdu w międzynarodowej infrastrukturze komunikacyjnej UE. *TEKA* KMRiL, Wyd. PAN O/Lublin, tom 8A, 10-15.
2. **Burski Z., Mijalska-Szewczak I. 2009.** Analiza parametrów trakcyjnych jazdy pojazdu w infrastrukturze autostrady metodą statystyczną WPR. *TEKA* KMRiL, Wyd. PAN O/Lublin, tom 9, 11-19.
3. **Burski Z., Mijalska-Szewczak I. 2010.** An analysis of AETR act standards realization in global domestic and international logistics. *TEKA* KMRiL, Wyd. PAN O/Lublin, tom 10, 27-32.
4. **Burski Z., Mijalska-Szewczak I. 2011.** Analiza wydatkowania energii kinetycznej pojazdu w szkoleniu zawodowym kierowców na podstawie zapisu tachograficznego. *Autobusy - Technika, Eksploatacja, Systemy Transportowe,* nr 10, 85-91.
5. **Burski Z., Krasowski E. 2011.** Zastosowanie rozkładu prawdopodobieństwa amplitud prędkości jazdy w badaniach energochłonności pojazdu. *MOTROL*, Wyd. PAN, O/Lublin - UR Lwów (Dublany), tom 13D, Lwów, 27-32.
6. **Burski Z., Krasowska-Kołodziej H. 2012.** Modelowanie strat energii kinetycznej pojazdu na podstawie sumarycznej częstości parametrów - profilu prędkości jazdy. *MOTROL*, Wyd. PAN, O/Lublin (w druku).
7. **Gaca S. 2001.** Zarządzanie prędkością jako środek poprawy bezpieczeństwa ruchu drogowego. Mat. konferencyjne. BRD Lublin, 187-207.

8. **Korobetsky Y., Sokolova Y., Doroshko V. 2010.** Imitation abstract model of production systems. Com. of Mat. and Power Industry in Agriculture, PAN O/Lublin - DE UNU Lugansk, Ukraine. *TEKA*, vol. XA, 285-293.
9. **Kostyrko L. 2010.** The mechanism of the stable development financial strategy of an enterprise. Methodology and Organization. Com. of Mot. and Power Industry in Agriculture, PAN O/Lublin - DE UNU Lugansk, Ukraine. *TEKA*, vol. XA, 303-310.
10. **Kubiński A. 2008.** Model symulacyjny sterowania zużyciem paliwa z uwzględnieniem warunków zewnętrznych. UW - M. Olsztyn.
11. **Lahno V., Petrov A. 2010.** Tasks and methods of the static optimum encoding of service request priorities in the information protection system of local area network. *TEKA*, vol. XA, 351-360.
12. **Maksimova T., Shapran E. 2010.** Approach to diagnostics of marketing complex of industrial enterprise. Com. of Mat. and Power Industry in Agriculture, PAN O/Lublin - DE UNU Lugansk, Ukraine. *TEKA*, vol. XB, 2-11.
13. **Madej B., Michniak J., Madej R. 2007.** Tachografy cyfrowe. Wyd. ATiP, Sp. z o.o. Warszawa, 49-50.
14. **Mijalska-Szewczak I. 2010.** System Eco-Driving w teorii, eksperymencie i praktyce eksploatacyjnej pojazdu logistyki transportowej. *Autobusy - Technika, Eksploatacja, Systemy Transportowe,* nr 10, 40-47.
15. **Nechaev G., Luchko M. 2010.** The position of diagnostics and motor - service in transport – logistic system of the Ukraine. Com. of Mat. and Power Industry in Agriculture, PAN O/Lublin - DE UNU Lugansk, Ukraine. *TEKA*, vol. XB, 65-71.
16. **Ramazanov S. 2010.** Innovative technologies of anticrisis management for production – transport complex. Com. of Mat. and Power Industry in Agriculture, PAN O/Lublin - DE UNU Lugansk, Ukraine. *TEKA*, vol. XB, 120-124.
17. **Shapovalov V., Nezhinskiy Y. 2010.** The evaluation technique of logistics system Cargo transportation efficiency development. Com. of Mat. and Power Industry in Agriculture, PAN O/Lublin - DE UNU Lugansk, Ukraine. *TEKA*, vol. XB, 162-170.
18. **Siłka W. 1998.** Analiza wpływu parametrów cyklu jezdnego na energochłonność ruchu samochodu. Wyd. PAN O/Kraków, zeszyt 14. Monografia, Kraków.
19. **Ubysz A. 2003.** Energochłonność samochodu a zużycie paliwa w złożonych warunkach ruchu. WT Politechnika Śląska, Gliwice.
20. **Zielińska E., Lejda K. 2010.** Analiza i modelowanie procesów logistycznych w zapleczu technicznym transportu samochodowego w aspekcie problemów ekologicznych. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów, 135-181.

WERYFIKACJA MODELOWANIA ENERGOCHŁONNOŚCI POJAZDU W WARUNKACH EKSPLOATACYJNYCH PRZEDSIĘBIORSTWA TRANSPORTOWEGO

Streszczenie. W pracy przedstawiono wyniki badań eksploatacyjnych samochodu w zmiennej infrastrukturze krajowej i międzynarodowej. Przedmiotem badań była ocena realizacji ustawy AETR oraz wpływu infrastruktury i wykorzystania ładowności pojazdu na zużycie paliwa (konwencjonalne i energii rozproszonej). W obliczeniach wykorzystano formalizm matematyczny przyjętego modelu strukturalnego.

Słowa kluczowe: logistyka transportowa, infrastruktura komunikacyjna, modelowanie strukturalne, czynniki eksploatacyjne, zużycie paliwa, zapis cyfrowy.