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Kinetics Modelling Service Verification of Vehicle Speed Using the Statistical Significance in an Urban Food Distribution

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Summary. This paper presents the results of statistical analysis of the mathematical significance of the speed transition phases changes in operational conditions. The analysis was based on tachograph speed recording waveforms obtained in the conditions of urban food distribution. It has been shown that the smallest statistical variability of cooling cars speed waveforms involves a reaction of drivers in urban transport infrastructure.
Key words: energy consumption in transport, urban food distribution, speed, acceleration and deceleration phases, statistical significance of overlap.

INTRODUCTION

Transport food economy forces the fulfillment of specific requirements and transport solutions in terms of quality of services offered and the associated costs. This includes time requirements, which include speed (time) of delivery and timeliness [9, 10].

The speed of delivery is an important requirement, since the short time has its definite advantages, such as [13, 15, 17]:

- kick-start of the production or sale of the product,
- short rotation of current assets frozen during the transport of goods,
- less risk of damage during transportation (e.g. animals – stress, weight loss, etc.),
- possibility to reduce storage space or the number of stationary points for stock along the route,
- possibility to obtain a higher price for high quality promptly-transported fruits, vegetables, dairy products, etc.,
- increase of the market competitiveness of plant or animal products.

An extremely important factor, demonstrating the quality of transport services in the food industry is the safety of cargo, which also depends on the environment in which the transport takes place. The type of environment has a big impact especially in road transport, with a significant share in the transport of food, due to possible collisions and accidents etc. It may take place on congested and frequently bad roads and in varying weather conditions.

The issue of energy consumption in transport, due to the far-reaching consequences for the environment, is currently an important research issue, not only for the environment of transport routes, but especially for the environment of urban agglomeration [6, 8, 12, 16 , 20].

The kinetic phases of speed acceleration and deceleration play an important role in the issues of vehicle motion theory related to power consumption in vehicles [21]. The general considerations on their character can be found in the works by Silkie [18, 19], and they have been verified by urban and extra-urban tests. However, as studies by other authors have shown [1, 2, 3], during smooth driving under operating conditions the operator – vehicle driver must show many non-standard features and high efficiency in the following areas: reception of information, its processing and execution of the decision. Implementation of the decision is the final effect of determining driving style, which is recognized by tachograph record [4].

THE AIM OF STUDY

As is clear from the review of literature on these issues, in particular, research on energy-intensive vehicles or transport psychology, at present there is no unified theory based on mathetical significance of the interaction of many factors. There is no theory which would explain exhaustively (at the appropriate probability level of its occurrence) a complete behavioral mechanism of a person driving a vehicle on the road or operating a machine. Nevertheless, there are attempts to quantitatively assess the energy consumption of a vehicle in terms of the relevance of interactions occurring in the already developed model of an Intelligent Transport

System (ITS_{SAT}) in the food industry [11], for example, in terms of expenditure of kinetic energy associated with the style of driving in variable road conditions, while operating a vehicle or learning driving, etc.

The aim of the present work is an attempt to determine the energy consumption of a vehicle in terms of quantitative evaluation of its driver's reaction in acceleration and deceleration speed phases in the conditions of town and city food distribution.

THE RESEARCH METHODOLOGY AND STATISTICAL CALCULATIONS

The basis of the adopted statistical methodology of the general kinetic model phases of acceleration and deceleration speeds [18] was the analysis of the statistical significance of their occurrence in the conditions of transport in town (provincial and district) and city (the capital) infrastructure. Boundaries were evaluated of waveforms of continuous driving speed recorded by tachographs of the vehicles used in accordance with the AETR Agreement [14].

The object of study were refrigerated vehicles used for urban food distribution.

This paper presents the results of research on vehicles in the spatial domain of the considered model. In contrast, studies of vehicles in the time domain will be the subject of further studies after obtaining the proper, statistically significant number of measurements.

To assess the significance of their occurrence, the basic statistical calculations were selected: tests number and then populations, showing significant differences among variables in terms of the mean, median, and measures of variability (variance, standard deviation, coefficient of variation) [5, 22].

STATISTICAL ANALYSIS OF THE TRANSITION SPEED PHASES IN THE CONDITIONS OF URBAN AGGLOMERATION

THE BASIC SIZES OF THE SET AND THEIR VARIABILITY CHARACTERISTICS

The basic values of set assessment according to the requirements of traffic engineering [7], i.e, the arithmetic mean and median statistics of speed waveform parameters in Lublin are higher in the acceleration phase (Table 1a), and the characteristics of their changes, i.e, variance, standard deviation, coefficient of variation are higher in the deceleration phase (Table 1b).

The statistical values of speed waveform in Biłgoraj show a similar behavior, assuming essentially higher values for the basic parameters (mean, median) in the acceleration phase (Table 2a). For the parameters describing their variability in the deceleration phase (Table 2b).

The smallest statistical variability of speeds was recorded in Warsaw in the acceleration phase, the coefficient of variation was in the range 7.3 – 16.1 % (Table 3a). This was also confirmed by the deceleration phase, the coefficient of variation was similar: 10.8 – 25.4% (Table 3b).

TESTING THE SIGNIFICANCE OF DIFFERENCES IN MEANS AND VARIANCES OF STATISTICAL PARAMETERS DURING PHASES OF ACCELERATION AND DECELERATION

The calculation results of t-Student tests (assuming equal means $H_o: \mu_1 = \mu_2$) and F- Snedecor tests (assuming equal variances $H_o: \sigma^2_1 = \sigma^2_2$) of the statistical parameters of acceleration and deceleration phase of speed in Lublin, Warsaw and Biłgoraj are shown in Tables 4-6.

Table 1a. A set of statistical values of speed waveform (Lublin)

Specification Number		Statistical parameters of acceleration phase						
		Arithmetic mean	Variance	Standard deviation	Median	Mode	Coefficient of variation [%]	
Statistical characteristics of set	Mean	124,32	37,49	281,02	16,55	35,54	37,01	46,79
	Median	127	38,29	255,71	15,99	37,7	35,5	42,2
	Variance	986,58	87,61	8172,16	7,08	137,59	177,16	154,75
	Standard deviation	31,41	9,36	90,4	2,66	11,73	13,31	12,44
	Coefficient of variation [%]	25,3	25	32,2	16,1	33	35,9	26,6

Table 1b. A set of statistical values of speed waveform (Lublin)

Specification Number		Statistical parameters of deceleration phase						
		Arithmetic mean	Variance	Standard deviation	Median	Mode	Coefficient of variation [%]	
Statistical characteristics of set	Mean	104,16	20,30	236,34	14,6	25,69	16,41	76,13
	Median	90	20,07	230,09	15,17	25,62	14,28	70,7
	Variance	2885,84	51,84	20486,2	23,04	257,02	139,01	449,86
	Standard deviation	53,72	7,2	143,13	4,8	16,05	11,79	21,21
	Coefficient of variation [%]	51,6	35,4	60,6	32,9	62,5	71,9	27,9

Table 2a. A set of statistical values of waveform speeds (Biłgoraj)

Specification Number		Statistical parameters of acceleration phase						
		Arithmetic mean	Variance	Standard deviation	Median	Mode	Coefficient of variation [%]	
Statistical characteristics of set	Mean	132,63	43,44	313,61	17,19	42,57	74,06	40,41
	Median	141	40,85	277,6	16,66	43,1	60	38,8
	Variance	5273,66	98,21	26351	18,06	669,77	2072,07	101
	Standard deviation	72,62	9,91	162,33	4,25	25,88	45,52	10,05
	Coefficient of variation [%]	54,8	22,8	51,8	24,7	60,8	61,5	24,9

Table 2b. A set of statistical values of waveform speeds (Biłgoraj)

Specification Number		Statistical parameters of deceleration phase						
		Arithmetic mean	Variance	Standard deviation	Median	Mode	Coeficient of variation [%]	
Statistical characteristics of set	Mean	96,47	22,76	327,65	17,29	28,98	31,07	83,71
	Median	62	18,97	276,92	16,64	25,63	23,33	77,8
	Variance	4356	149,57	39223,8	28,62	278,56	1457,71	580,33
	Standard deviation	66	12,23	198,05	5,35	16,69	38,18	24,09
	Coefficient of variation [%]	68,4	53,7	60,5	30,9	57,6	122,9	28,8

Table 3a. A set of statistical values of waveform speeds (Warsaw)

Specification Number		Statistical parameters of acceleration phase						
		Arithmetic mean	Variance	Standard deviation	Median	Mode	Coefficient of variat [%]	
Statistical characteristics of set	Mean	148,2	56,54	241,12	15,48	60,1	55,09	27,56
	Median	150	56,3	249,72	15,8	58,14	57,06	26,8
	Variance	245,86	17,14	1498,46	1,61	33,64	68,06	12,6
	Standard deviation	15,68	4,14	38,71	1,27	5,8	8,25	3,55
	Coefficient of variation [%]	10,6	7,3	16,1	8,2	9,7	15	12,9

Table 3b. A set of statistical values of waveform speeds (Warsaw)

Specification Number		Statistical parameters of deceleration phase						
		Arithmetic mean	Variance	Standard deviation	Median	Mode	Coefficient of variation [%]	
Statistical characteristics of set	Mean	137,2	22,54	553,13	23,29	10,16	5,85	106,8
	Median	144	23,72	571,49	23,91	9,72	6,15	99
	Variance	218,45	26,52	19773,9	10,56	1,17	1,74	241,18
	Standard deviation	14,78	5,15	140,62	3,25	1,08	1,32	15,53
	Coefficient of variation [%]	10,8	22,8	25,4	14	10,7	22,6	14,5

The calculation results of t-Student test on the driving speed in Lublin (Table 4), did not show significant differences in case of variance and standard deviation. For other statistical parameters, significant differences were observed. For example, for the speed mode the obtained value t_{obl} = 5,68 lies both in the critical area K = (1,67; ∞) for one-tailed test (the alternative hypothesis H_1: $\mu_1 > \mu_2$)), and in the critical area K = (-∞; -2) U (2; ∞) for two-tailed test (alternative hypothesis H_1: $\mu_1 \neq \mu_2$). The size of the difference calculated according to the relevant literature [22] is 13,34 < $\mu_1 - \mu_2$ < 27,86, which shows that the mean speed mode in the acceleration phase is higher than the mean speed mode in the deceleration phase at least by about 13.34 km/h, and at most by 27.86 km/h (level of significance α = 0.05).

The calculation results of t-Student test for the significance of occurrence of acceleration and deceleration speed phases in Biłgoraj (Table 5) are as follows: in the case of variance (t_{obl} = -0,23) and standard deviation (t_{obl} = -0,06) there are no significant differences for one-tailed [H_1: $\mu_1 < \mu_2$; K = (-∞; -1,69)] and two-tailed [H_1: $\mu_1 < \mu_2$; K = (-∞; -1,69)] tests. In the case of the median at the significance level α = 0.05 (two-tailed test) there are no significant difference, but on the significance level α = 0.1 (one-tailed test) there are.

Calculations of the significance of differences between means at acceleration and deceleration speed phases in Warsaw (Table 6) showed that for all the statistical parameters they are significant. For example, the difference between the median speed means at acceleration and deceleration

Table 4. The calculation results of t-Student and F- Snedecor tests on statistical parameters during speed phases of acceleration and deceleration in Lublin

Specifi cation	Arithmetic mean	Median	Mode	Variance	Standard deviation	Coefficient of variation
	Max/Min	Max/Min	Max/Min	Max/Min	Max/Min	Max/Min
Mean	37,49/20,34	35,54/25,69	37,01/16,41	281,02/236,34	16,55/14,6	46,79/76,13
Variance	87,61/51,84	137,59/257,02	177,16/139,01	8172,16/20486,2	7,08/23,04	154,75/449,86
Observation	25/25	25/25	25/25	25/25	25/25	25/25
Test of t-Student for difference of means: df/t_{obl}	48/7,11	48/2,43	48/5,68	48/1,29	48/1,64	48/-5,85
$t_{\alpha=0,1}$ (one-tailed test)	1,67	1,67	1,67	1,67	1,67	1,67
$t_{\alpha=0,05}$ (two-tailed test)	2,0	2,0	2,0	2,0	2,0	2,0
Test of F-Snedecor for difference of variance: $df_1;df_2/F_{obl}$	24;24/1,69	24;24/1,87	24;24/1,91	24;24/2,51	24;24/3,25	24;24/2,91
$F_{\alpha=0,05}$	1,98	1,98	1,98	1,98	1,98	1,98

Table 5. The calculation results of t-Student and F- Snedecor tests on statistical parameters during speed phases of acceleration and deceleration in Biłgoraj

Specifi cation	Arithmetic mean	Median	Mode	Variance	Standard deviation	Coefficient of variation
	Max/Min	Max/Min	Max/Min	Max/Min	Max/Min	Max/Min
Mean	43,44/22,76	42,57/28,98	74,06/31,07	313,61/327,65	17,19/17,29	40,41/83,71
Variance	98,21/149,57	669,77/278,56	2072,07/1457,71	26351/39223,8	18,06/28,62	101/580,33
Observation	19/19	19/19	19/19	19/19	19/19	19/19
Test t-Student for difference of means: df/t_{obl}	36/5,57	36/1,87	36/3,07	36/-0,23	36/-0,06	36/-7,04
$t_{\alpha=0,1}$(one-tailed test)	1,69	1,69	1,69	1,69	1,69	1,69
$t_{\alpha=0,05}$ (two-tailed test)	2,03	2,03	2,03	2,03	2,03	2,03
Test F-Snedecor for difference of variance: $df_1;df_2/F_{obl}$	18;18/1,52	18;18/2,4	18;18/1,42	18;18/1,49	18;18/1,58	18;18/5,75
$F_{\alpha=0,05}$	2,22	2,22	2,22	2,22	2,22	2,22

Table 6. The calculation results of t-Student and F- Snedecor tests on statistical parameters during speed phases of acceleration and deceleration in Warsaw

Specification	Arithmetic means	Median	Mode	Variance	Standard coefficient	Coefficient of variability
	Max/Min	Max/Min	Max/Min	Max/Min	Max/Min	Max/Min
Mean	56,54/22,54	60,1/10,16	55,09/5,85	241,12/553,13	15,48/23,29	27,56/106,8
Variance	17,14/26,52	33,64/1,17	68,06/1,74	1498,46/19773,9	1,61/10,56	12,6/241,18
Observation	5/5	5/5	5/5	5/5	5/5	5/5
Test t-Student for the difference of means: df/t_{obl}	8/10,29	8/16,9	8/11,79	8/-4,28	8/-4,48	8/-9,95
$t_{\alpha=0,1}$ (one-tailed test)	1,86	1,86	1,86	1,86	1,86	1,86
$t_{\alpha=0,05}$ (two-tailed test)	2,31	2,31	2,31	2,31	2,31	2,31
Test F-Snedecor for difference of variance: $df_1;df_2/F_{obl}$	4;4/1,55	4;4/28,75	4;4/39,11	4;4/13,19	4;4/6,56	4;4/19,14
$F_{\alpha=0,05}$	6,39	6,39	6,39	6,39	6,39	6,39

phases is in the range $43.13 < \mu 1 - \mu 2 < 56.75$ (significance level $\alpha = 0.05$).

Also, the null hypothesis was verified, of equality of variances $H_0 : \sigma^2_1 = \sigma^2_2$ against the alternative hypothesis H_1: $\sigma^2_1 > \sigma^2_2$, tj., i.e. the value $F_{obl} = n_1 \sigma^2_1/n_1 - 1 : n_2 \sigma^2_2/n_2 - 1$ [22] was determined.The critical area designated from the arrays of F – Snedecor test is $K = (F_{\alpha = 0,05}; \infty)$. In the range of mean, median and mode of the acceleration and deceleration speed phases in Lublin (Table 4), the calculated values of the test function are, respectively, $F_{obl} = 1,69$, $F_{obl} = 1,87$ and $F_{obl} = 1,91$ and they lie outside the critical area $K = (1,98; \infty)$. Hence, the variance values of these variables are not significantly different, and the null hypothesis was fulfilled. In the case of the city Bilgoraj (Table 5), for the median and coefficient of variation there are significant differences ($F_{obl} > F_{\alpha = 0,05}$), for the other statistical parameters there are none. Furthermore, the verification calculations of the hypothesis of equality of variance between the driving speeds during acceleration and deceleration phases in Warsaw (Table 6) showed that only for the mean velocity range it is true is, i.e. $F_{obl} = 1,55 < F_{\alpha = 0,05} = 6,39$.

CONCLUSIONS

The analysis of electronic record of a vehicle's speed in the urban conditions of food distribution allows for the shortening of transport by the fast, optimal selection of both the vehicle and route for a specific transport task . The basis is to optimize the driving technique of the vehicle (traction parameters). So, study on the use of electronic analysis of the operation are used to determine energy-efficient (economic) driving routes in the distribution of food products, e.g. from the manufacturer (wholesaler) to the collection point, which is now an important transport problem for cities and may increase transportation costs.

The developed research material in the field of kinetic energy expenditure during the acceleration and deceleration speed phases allowed for the determination of both the general conclusions of cognitive nature and the specific ones as to the obtained statistical significance of changes in the boundary of tachograph recording waveform in the conditions of urban food distribution.

COGNITIVE CONCLUSIONS

1. Tachograph record is the basic, technical, legislative and final record of the driver's reaction, which reflects both the kinetics of the vehicle and the characteristic features studied by the transport psychology.
2. In place of the previously used models of kinetic energy expenditure, or the driver's psychological models, the in-service model type should be used, the so-called Intelligent Transportation System based on the SAT system, taking into account both the interactions occurring in space (statistical number of vehicles on the section of the infrastructure) and the time domain, considering the long term "energetic reactions" of the driver
3. Analysis of energy consumption of the vehicle associated with the style of its operation is an important factor in the impact of transport on the environment in every urban and transport infrastructure.

SPECIFIC CONCLUSIONS AND DEVELOPMENT

1. The smallest variability of the analyzed statistical parameters expressed in coefficient of variation was obtained for the speeds waveform in Warsaw, in both kinetic phases. In smaller cities (Lublin, Biłgoraj, coefficients of variation reach higher values.
2. The basic statistical values of the set (mean, median) are higher in the acceleration phase, and their variability factors (variance, standard deviation, coefficient of variation) assume higher values in the speed deceleration phase.
3. The tests of difference significance for the means of the analyzed parameters showed significant differences in both speed phases in Warsaw. For the other cities, no significant difference exists only in the case of variance and standard deviation of speed in acceleration and deceleration phases. In the case of median there is no clear cut.
4. Verification of the hypothesis of equality of variances of the two speed phases in Lublin showed that it met the basic statistical parameters, while significant differences concerned the parameters assessing their variability. Equality of variance occurred only in the case of mean speed in Warsaw, and in relation to the speed waveform in Biłgoraj it concerns not only the median and coefficient of variation.

On the basis of the obtained specific conclusions it should be noted that the food distribution drivers' behavior in urban infrastructure points at energy-efficient driving, and thus lower harmful impact on the environment. This is also related to better solutions for transport infrastructure, longer sections of continuous driving, using the green line, etc. [7].

The mathematical analysis of statistical significance gives a quantitative assessment of change at a given level of probability, and the use of digital recording (up to 40 000 sampling values) provides basically endless possibilities for research that will continue in studies realized in the food industry.

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EKSPLOATACYJNA WERYFIKACJA MODELOWANIA KINETYKI PRĘDKOŚCI JAZDY POJAZDU METODĄ ISTOTNOŚCI STATYSTYCZNEJ W WARUNKACH MIEJSKIEJ DYSTRYBUCJI ŻYWNOŚCI

Streszczenie. W pracy przedstawiono wyniki statystycznej analizy matematycznej istotności zmian faz przejściowych prędkości jazdy w warunkach eksploatacyjnych. Analizę przeprowadzono w oparciu o oscylogramy zapisu tachograficznego prędkości jazdy, uzyskane w warunkach miejskiej dystrybucji żywności. Wykazano, że najmniejsza zmienność parametrów statystycznych oscylogramu prędkości jazdy samochodów chłodniczych dotyczy reakcji kierowców w wielkomiejskiej infrastrukturze komunikacyjnej.

Słowa kluczowe: energochłonność transportu, miejska dystrybucja żywności, prędkość jazdy, fazy przyspieszania i opóźniania, istotność statystyczna zachodzenia.