Available Online at http://www.journalajst.com

ISSN: 0976-3376

ASIAN JOURNAL OF
SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 09, Issue, 12, pp.9060-9072, December, 2018

RESEARCH ARTICLE

THE IDEA OF CHOICE OF STEERING WHEEL INPUT PARAMETERS IN RELATION TO BASIC CONDITIONS OF MANOEUVRE EXECUTION

[1]Tomasz Lech Stańczyk and [2,*]Dariusz Więckowski

[1]Professor and Ph.D. Engineering the Kielce University of Technology, Department Mechatronics and Machine Building Kielce
[2]Engineering, Automotive Industry Institute, Warszawa, Poland

ARTICLE INFO

Article History:
Received 19th September, 2018
Received in revised form
24th October, 2018
Accepted 20th November, 2018
Published online 20th December, 2018

Key words:
Optimisation, Correct Execution of Manoeuvre, Creating of Steering Assisted system, Simulation of Manoeuvres.

ABSTRACT

The work includes problems of creating of steering assisted system in field of realization of curvilinear traffic. This paper presents problems of analysis of correct execution of manoeuvres. It presents objective function, which enables to evaluate correct execution of manoeuvres. Tapering coefficients are discussed. The paper presents the conception of realization of curvilinear traffic based on principle "recognizing the manoeuvre as complex element". Computer simulation results are presented. They have enabled the working out of a range of values of steering wheel input function.

Citation: ***Tomasz Lech Stańczyk and Dariusz Więckowski*, 2018.** "The idea of choice of steering wheel input parameters in relation to basic conditions of manoeuvre execution", *Asian Journal of Science and Technology*, 09, (12), 9060-9072.

INTRODUCTION

In the safety system, of which the elements are: the human being, the vehicle and its surroundings, the weakest link is the human. However practice shows that the possibilities of increasing safety solely through the acting on the "human factor" are severely limited. For a longer period of time (without neglecting activity intended to increase the ability and responsibility of drivers) the aspiration has been toward such a shaping of the characteristics of the vehicle and its equipment with such appliances and auxiliary systems (Stańczyk T.L., 1998), so that despite the disabilities in thought and character traits of the human driver, the vehicle shall assure the greatest safety in travel. One might say that our aspiration is that the vehicle would compensate for the faults and deficiencies of the driver. The most radical approach is the concept of creating an automatic system to drive the vehicle, sometimes referred to as "automatic pilot". Currently the prevailing view is that full automation of the vehicle should be considered rather as a remote objective. Recently research has been concentrated on the creation and development of so-called assistant systems (Jürgensohn and Timpe, 2001).

***Corresponding author:* Dariusz Więckowski,**
Engineering, Automotive Industry Institute, Warszawa, Poland.

In the immediate future such solutions shall be required in new vehicles, shall enable the introduction of ever better steering appliances, with assistance, without impeding the driver in the possibility of their use. The aspiration is to combine the maximum quantity of individually operating system in groups or in one collective system. Recently the concept has appeared of an auxiliary system described as an "assistant system", as a new concept of vehicle development (Busch S., 2005), (Henning K., Preuschoff E., 2003), (Jürgensohn T., Timpe K.P., 2001), (Müller M., 2005) and (Wiltschko T., 2004). Their operation consists of the manoeuvre being initiated by the driver (the wish to accelerate, brake or turn), while the assistant system ("assistant") based on data from sensors on the state of movement and information about the surroundings, using dynamic models enabling the envisaging of the results of the planned manoeuvre, permits its execution or corrects its course through the limitation of certain activities (parameters), if the result might be the loss of stability or collision etc. Also in the extent of the development of such systems or performed in parallel subjects connected with the optimisation of road manoeuvres, e.g. publications (Gerdts M., 2003), (Gordon T.J., 2006) and (Pohl. J. Sethsson M., Degerman P., Larsson J., 2006).Systems such as in the extent of steering, the so-called longitudinal vehicle dynamic, are already sufficiently well refined and commonplace e.g.:

ABS, ASR, ICC and others. Greater difficulty is caused by preparing steering systems for curvilinear movement. Many proposed solutions exist; yet they are a long way from the level, which would enable their introduction in practice. Generally speaking these systems will not be in a state in the very short time to perform the steering loop consisting of: collecting information (e.g. image) of the shape of the track, the analysis of this information, prepare a decision and transmit steering signals to the execution systems and perform the planned functions (of the appropriate trajectory correction). Among attempts to resolve this problem one may distinguish two trends. The first is the improvement of elements of the implementation system of the above-described algorithm of operation. Mainly this concerns a significant increase in speed and reliability of collection and analysis of information on surroundings. The second trend – are attempts at another solution of the problem, going beyond the first convention. An example here might be the original model driver proposed in the works K. Yoshimoto (Yoshimoto K., Iwatani K., Kokubo T., 1997), (Yoshimoto K., Obawa H., Kubota H., 1997), using the so-called "optical flow" method. This article is a piece of a larger work, in which the concept of assisted curvilinear movement performance is analysed assuming that the steering system shall "recognise" ("see") the manoeuvre as a whole, that is it shall possess the implemented algorithms (strategies) of correct manoeuvre performance.

Manoeuvre correctness evaluation criteria: In order to draw up algorithms for the correct performance of manoeuvres it is first necessary to formulate criteria for the correct execution of the manoeuvre. In connection with this it is necessary to define, which traits should characterise correct execution of the manoeuvre. Assuming that the vehicle should adhere to the travel track in the defined traffic lane, simultaneously avoiding violent movements, and thus ensure a feeling of comforTable travel for passengers – one may propose the following manoeuvre correctness evaluation criteria:

- Precision of movement track performance – adherence to the defined lane,
- Calm steering – avoiding violent, frequent movement of the steering wheel,
- Feeling of comforTable travel for passengers.

As a measure of the above criteria one may accept various physical quantity. The feeling of passenger comfort may be evaluated with the aid of the rapidity of lateral acceleration a_y, the angle of inclination of the vehicle body Φ_1 or the yaw velocity of the vehicle body $\dot{\Phi}_1$. Precision of accomplishment of the vehicle movement track may be evaluated by change in the distances between the line limiting the traffic lane and a edge of the vehicle or deviation from the designated movement track. Calmness of steering may be defined in the measure of the steering wheel angle δ_H, but also in the steering wheel angular velocity $\dot{\delta}_H$ or the steering wheel angular acceleration $\ddot{\delta}_H$. One may also make use of the costs of the steering wheel angle in the time function δ_H (t). Valuable premises for the choice of size being the nature of the above-formulated criteria may be found in analysing tests applied in testing the steerability and stability of vehicles. Practically in all of the above tests lateral acceleration a_y is registered. It is a leading parameter in tests frequently determined as a basic quantity, e.g. a_{ymax} or as "auxiliary", e.g. for the determination of characteristics such as $\delta_H(a_y)$.

As one of the measured values it appears e.g. in tests: (ISO12021, 1994), (ISO4138, 1996), (ISO7975, 1996), (ISOTR3888, 1975), (ISOTR8726, 1988) and (ISO/DIS7401, 2000). Often it is determined in the form of time characteristics $a_y(t)$ – e.g. in tests: (ISO12021-1, 1996), (ISO7975, 1996), (ISO9816, 1993), (ISOTR3888, 1975), (ISOTR8725, 1988) and (ISO/DIS7401, 2000). As a measure of maximal value a_{ymax} appears e.g. (ISO/DIS7401, 2000). Adherence to the defined movement track may be directly designated as lateral deviation - determined in tests (ISO12021, 1994) and (ISO12021-1, 1996) or change of trajectory of movement of the centre of mass, or change of curvature of the movement track - e.g. test (ISO9816, 1993). In other tests (e.g. (ISO7975, 1996), (ISOTR3888, 1975), (ISOTR8725, 1988) and (ISO/DIS7401, 2000)) for the definition of deviation from the assumed movement track use is made of the quantities: angular velocity of deviation or value of the slip angle. Adherence to the assume movement track may equally be otherwise evaluated, namely through the maximal value of speed, with which one may travel on the assumed track – e.g. test (ISO3888-1, 1999), (ISOTR3888, 1975) and (ISO/DIS3888-2, 2000). Calm steering is directly connected with rotation of the steering wheel. The value of the steering wheel angle δ_H appears in the majority of tests ISO. Often the main purpose of testing is the designation of characteristic: $\delta_H(t)$ –e.g. in tests (ISOTR3888, 1975), (ISOTR8725, 1988) and (ISO/DIS7401, 2000) or $\delta_H(a_y)$ – e.g. test (ISO4138, 1996). Significantly more seldom does it appear in tests as a parameter of steering wheel angular velocity – test (ISO 7401, 1998), (ISOTR8725, 1988) and (ISO/DIS7401, 2000).

On the basis of particular analysis of tests (only signalled here) three quantities are chosen, as formulated measures of the above evaluation criteria of manoeuvre correctness (one for each criterion).

- For the evaluation of precision of accomplishment of the movement track of the vehicle is accepted the minimal distance of the vehicle body from the edge of the traffic lane obtained during the performance of the manoeuvre with regard for the adherence of the vehicle to the assumed movement track.
- To evaluate calm driving the steering wheel angular velocity is used. However in this instance a single value has not been decided on (e.g. maximal) speed of angle, but over the course of the entire extent of manoeuvre. The effect of acceptance of only one value, for example the maximal, would have no regard for multiple steering wheel movement (jerks), with much smaller values than the maximal.
- For the evaluation of passenger comfort the value of the maximal lateral acceleration is accepted a_{ymax} that occurs during performance of the manoeuvre. In this instance acceptance of the roll angle of the vehicle body (it's roll velocity or roll acceleration) would not be reliable, because, e.g. at small roll angles of the vehicle may obtain great lateral acceleration.

Very similar criteria are applied in work (Yoshimoto K., Obawa H., Kubota H., 1997). With regard to the above described manoeuvre correctness evaluation criteria it is accepted that to build the criterion function, serving to evaluate manoeuvre correctness, three components are used:

Table 1. Values of coefficients w_1, w_2 and w_3 in travel speed function

Vehicle speed (km/h) ((m/s))	Coefficient w_1 (s^2/rad^2)	Coefficient w_2 ($1/m^2$)	Coefficient w_3 (s^4/m^2)
0 (11.11)	0.80	1.0	0.30
60 (16.67)	0.80	1.0	0.40
80 (22.22)	0.80	1.0	0.50
100 (27.78)	0.80	1.0	0.75
120 (33.33)	0.80	1.0	1.00

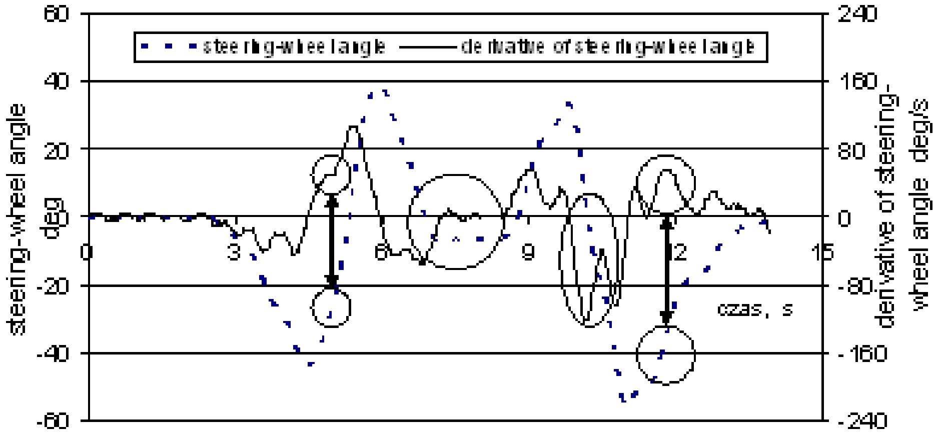

Fig. 1. Course of input for manoeuvre of double change of traffic lane

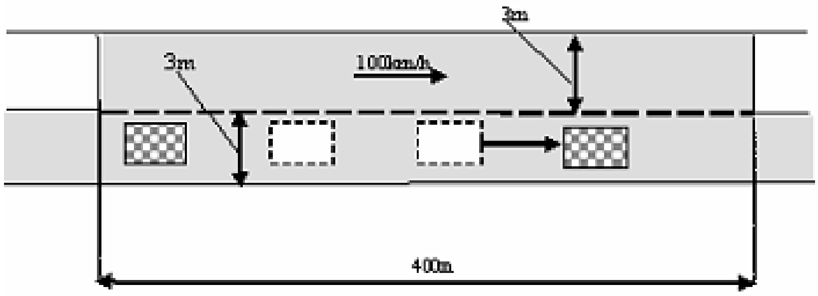

Fig. 2. "Overtaking" manoeuvre corridor

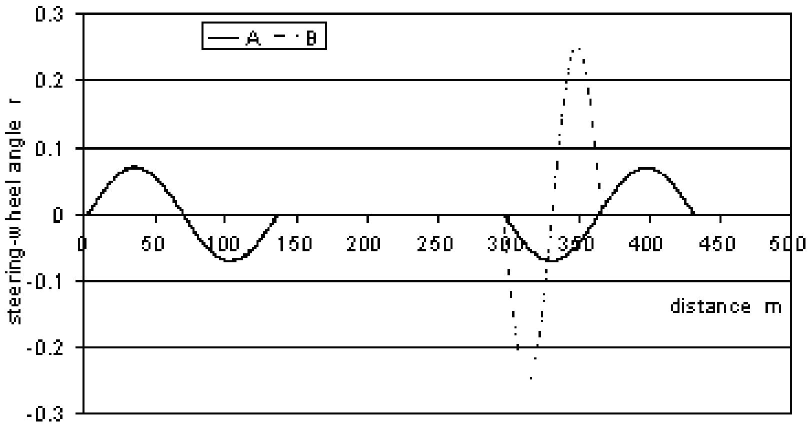

Fig. 3. Steering wheel input for the manoeuvre" overtaking" "A" and "B"

$\kappa = \frac{1}{\varepsilon}$ - reversibility of distance from edge of traffic lane, as a measure of precision of accomplishment of movement track, $\dot{\delta}_H$-steering wheel angular velocity, as a measure of calm steering, a_{ymax}-maximal lateral acceleration value, as a measure of feeling of passenger travel comfort. The last two are identical as in the work (Yoshimoto K., Obawa H., Kubota H., 1997).

The difference in the acceptance of the first component arises because in the quoted work the movement track is assumed and it is the centre of the traffic lane. In this work ε is the lateral deviation from the established track is regarded as a mistake in manoeuvre accomplishment. In this study the track is not set, but is the result of manoeuvre performance, while quantity ε designates the distance between

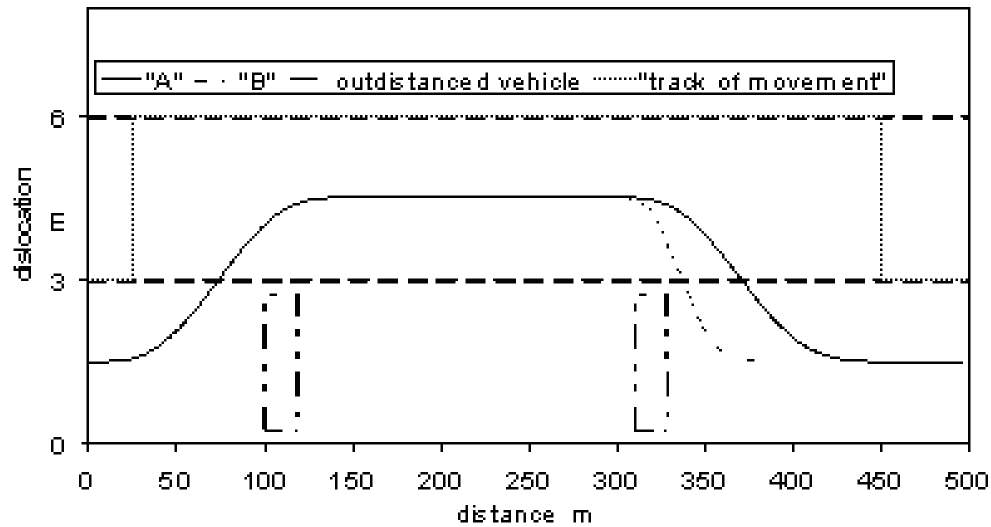

Fig. 4. Movement trajectory for “overtaking” manoeuvre” "A” and "B”

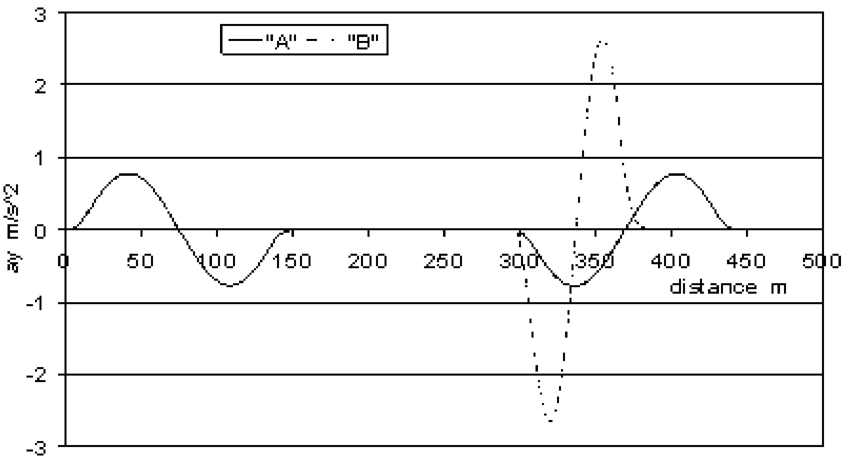

Fig. 5. Lateral acceleration for “overtaking” manoeuvre” “A” and “B”

Table 2. Criterion function value J_W and its components for examples “A” and “B”

	Evaluation of entirety	Calm steering		Precision of movement track achievement		Passenger travel comfort	
Designation course	Criterion function J_W	"1/Tintegral”	"1/Tintegral"* w_1	"kappa”	"kappa^2” * w_2	"aymax”	"aymax^2” * w_3
A	4.35	0.0041	0.0033	1.972	3.89	0.78	0.46
B	9.22	0.0695	0.0556	1.972	3.89	2.65	5.27

Table 3. Value: criterion function J_W and its components for manoeuvre “¼ roundabout”

Designation course	travel speed	J_W	"1/Tintegral”	"1/Tintegral” * w_1	"kappa”	"kappa^2” * w_2	"aymax”	"aymax^2” * w_3
1	25	8.15	2.353	1.882	2.270	5.153	2.72	1.11
2	25	627.89	2.295	1.836	25.000*)	625.000	2.65	1.05
3	20	8.60	1.861	1.489	2.604	6.781	1.81	0.33
4	30	10.81	3.165	2.532	2.270	5.153	3.95	3.12

*) exceeding permissible movement track width

the vehicle body, and one of the edges defining the width of the traffic lane. Thus in the measure of proximity to the line limiting the traffic lane the value ε shall diminish. Therefore its reversibility κ is accepted as a component of the criterion function. The accepted limitation concerning lateral acceleration a_y. Its value during the execution of manoeuvres should not exceed 4 m/s^2, and in exceptional cases it is permitted to reach the value of $7m/s^2$ (stipulated condition of removal of wheels from the road surface). It is parallel with the ISO tests e.g. (ISO7401, 1998), (ISOTR8725, 1998) and (ISO/DIS7401, 2000). The final criterion function, treated as a measure of correct manoeuvre execution, is accepted in the following forms similarly as in the work (Yoshimoto K., Obawa H., Kubota H., 1997):

$$J_W = w_1 \odot \frac{1}{T}\int_0^T \dot{\delta}_H^2\, dt + w_2 \odot \kappa_{max}^2 + w_3 \odot a_{y\,max}^2 \quad (1)$$

The components creating the criterion function (1) occur in the second power, due to which is obtained the reinforcement of the criterion and independence from the plus or minus sign of the given parameter.

Using the dynamic vehicle model built for this concept (with 12 degrees of freedom), presented in the work (Więckowski D., 2006), analysis is conducted of the course of manoeuvres in vehicle movement. The issue of evaluation of manoeuvre execution correctness, with the assumed (tested) function form of input acting on the steering wheel may be regarded as a task of optimisation including:

- Finding criterion function minimum – equation (1)
- Fulfilling limiting conditions:
- Vehicle adherence to given movement track,
- Adherence to lateral acceleration values in the permissible extent.

Choice of coefficients of criterion function: The choice of coefficients is based on analysis of the simulation of two manoeuvres: single and double change of traffic lane. Provisional simulations indicated that for these manoeuvres the most beneficial form of input function is the sinusoidal course of steering wheel angle. The purpose of the analysis was the search for optimal input parameters values (in this case amplitude A and input frequency f) for the given manoeuvre execution parameters, that is: traffic lane width and speed of travel. Defined permissible set in the form of a variability zone for two-dimensional problem

permissible set (variability zone) for A and f:

A = 0.01 to 4.00rad
f = 0.01 to 5.00rad/s

defined vehicle movement speed v = 40, 80 and 120km/h and width of traffic lane s_p = 3m;

The first step in the performance of the formulated task was to determine the values of coefficients "w_i", appearing in criterion function J_W (1). It is a very import and issue, if one wishes to consciously shape the influence of particular factors on the final evaluation. In order to do this, in the testing the coefficient value was initially accepted at $w_1= w_2= w_3=1$. This enabled testing, of how great is the influence (participation) of particular criterion function components J_W, on the final value of this function. Single and double change of traffic lane computer simulation was conducted for under steered and over steered vehicle, during which was registered this function value J_W and the values of its particular components. Calculation was performed by the systematic search method. Equally for an under steered as for and over steered vehicle the qualitative character of the influence of particular criterion function components J_W was approximate, only quantitative differences were noted.

The following designations are introduced to the description of the computer simulation results:

$\frac{1}{T}\int_0^T \dot{\delta}_H^2\, dt$ - “1/Tintegral” κ_{max}^2 - “kappa^2” $a_{y\,max}^2$ - “aymax^2”

As a point of reference the accepted value of the coefficient w_2, is taken giving it a fixed value equivalent to 1.00. Recognized as rational, submitted in work (24) recommendation, in order to place emphasis at low speeds on stability of steering, and at high speeds on the feeling of comfort. Thus it is accepted, that with the increase in speed the significance should increase of the component “aymax^2” (passengers' feeling of comfort), and the significance is reduced “1/Tintegral” (steering stability). One may accept that irrespective of travel speed for manoeuvres performed in a “mild” manner (“aymax”<0.5 m/s^2 and “1/Tintegral” <<0.5rad^2/s^2) of the greatest significance is the “kappa” value, that is manoeuvre accomplishment precision. Steering stability (“1/Tintegral” –coefficient “w_1”) has greater significance at low travel speeds, while travel comfort (“aymax” – coefficient “w_3”) has greater significance at high travel speeds. In connection with this one may state that with the increase of speed the participation of travel comforts increases at the cost of steering stability. On the basis of such accepted coefficients one may evaluate the values of coefficients for other intermediate speeds. As intermediate speeds 60km/h and 100km/h have been accepted. The last coefficient values accepted of travel speed function are given in Table 1.

Simulation testing: To present the concept of choice of input parameters applied steering wheel manoeuvre simulation is used: “double traffic lane change – overtaking” and passage through medium roundabout – “¼ roundabout”. Seeking premises for the formulation of the concept of manoeuvre performance with an assistance system, it was decided to observe, how (in a general sense) the human driver performs such a manoeuvre. In Fig. 1 is presented an example of steering wheel input (angle and angular velocity of steering wheel) performed by the driver for the double change of traffic lane manoeuvre. Analysing the movements of the steering wheel made by the driver it is seen that during the manoeuvre execution, the driver performs a flowing movement of the steering wheel according to the course accepted by himself. One may say that he has a certain vision of how the manoeuvre should be performed. Imperfection in thought obliges him however to make certain corrections during the manoeuvre. But after each correction he achieves a certain accepted manner of executing the manoeuvre. The presented results show that the driver perceives the manoeuvre as an entirety, and not as a series of very minor and very frequent corrections, such as take place in the achievement of automatic vehicle driving concepts.

The emphatic confirmation of this, is that the driver "sees" the manoeuvre as an entirety and endeavours to develop a concept for the achievement of the entire manoeuvre (successive repetitions of the manoeuvre) the driver already has a better impression (better conception) of the achievement of the manoeuvre as a whole. In subsequent passages (not shown in the sketch), the driver executed a smaller number of corrections. Simultaneously it should be stated that sometimes the corrections are so minor that they are not perceivable in the course outline of change of steering wheel angle. Only the derivative outline shows later at the given moment a certain correction was made for example the first and third correction on Fig. 1 – invisible on the angle line, observable on the derivative outline later. It arises from this unambiguously, that the driver performs a certain concept and during performance of the manoeuvre only corrects it (Więckowski D., 2006).

Double change of traffic lane – overtaking

The vehicle overtaken is a heavy goods vehicle and trailer combination moving at a speed of 70km/h. "Corridor" character in Fig. 2 arises from the following assumptions: width of traffic lane 3m, length of straight section d 400m, smallest visibility distance for overtaking 600m. In the case of this manoeuvre it is assumed that the overtaking driver travelling at a speed of 100km/h, undertakes the manoeuvre of overtaking the combination (lorry plus trailer). The driver is not surprised by the existing situation on the road and has time for a "calmly" executed manoeuvre. The task relied on such good input parameter values (amplitude A and input frequency f), in order to correctly execute the manoeuvre intended to minimise the criterion function J_W. For such a manoeuvre the optimal parameters values found characterising steering wheel input: $A_1 = A_2 = 0.07$rad; $f_1 = f_2 = 1.30$rad/s. For these criterion function values the minimal value is reached $J_W = 4.35$.

For comparison is placed the simulation reflecting the situation, if the driver begins an overtaking manoeuvre "calmly" (similarly to the first simulation), while in the final phase of the manoeuvre is forced to hasten its completion, e.g. because of another vehicle approaching from the opposite direction. For such a situation the optimal parameters values characterising steering wheel input amounted to: $A_1 = 0.07$rad and $A_2 = 0.25$rad and $f_1 = 1.30$rad/s and $f_2 = 2.50$rad/s, and criterion function reached the value of $J_W = 9.22$. For such a described situation the following designation of results is accepted: "A" – for the first simulation ($J_W = 4.35$); "B" – for the second simulation ($J_W = 9.22$). In Fig. 3 is presented the steering wheel input (steering wheel angle), and in Fig. 4 the movement trajectory achieved. Diagram on Fig. 5 shows that course of change of lateral acceleration during this manoeuvre. In these sketches that the broken line is covered in the first phase of a move for by the continuous line. In order to precisely evaluate both manoeuvre variants, in Table 2 are given the values of expressions being components of criterion function J_W. Comparing the above-described manoeuvres one may state that movement track precision is approximate -value "kappa" in Table 2. While the manoeuvre recognized as "better" ("A"), in relation to "B" (Table 2), is characterised by less (two rows of quantity) values of expression "1/Tintegral" (calmness of steering) - reducing e.g. momentary risk of loss of stability, if some fluid had been spilt on the road. Sudden movements of the steering wheel give large momentary values of lateral reaction on wheels. In the first variant is obtained furthermore decidedly less (over 3 times) the value of lateral acceleration "aymax". This means that significantly less lateral inertial force acts on the passengers. One may use the formulation, that in the event of manoeuvre "B" the passengers felt thrown to the sides. In the case designated as "B" it is interesting that despite the achievement of the initial phase of the manoeuvre in a "mild" and "calm" manner deciding on criterion function value J_W it showed the expressions "1/Tintegral" and "aymax" in the final manoeuvre phase. It may be stated, that in this case (according to the assumed diagram of Fig. 2) it is possible to safely and precisely execute manoeuvre (Fig. 4) in a "mild" manner ("calm" movement of the steering wheel Fig. 3). Simultaneously in a situation of danger (e.g. limitation of place for completion of overtaking manoeuvre) it is possible to complete the remover earlier, safely (from the point of view of adherence to movement track), however the increase of the value of lateral acceleration and the increase of value of roll angle of vehicle body occur. Travel through medium roundabout – "¼ roundabout". In Fig. 6 is presented a diagram of a medium two-lane roundabout.

Travel through the roundabout is an "assumed" manoeuvre, in connection with which it is divided into three stages:

- Entering the roundabout, characterised by rounded radius at entry R_{wej}, described in input parameters A_1 and f_1,
- Exit from roundabout, characterised by rounded radius at R_{wyj}, described in input parameters A_2 and f_2,
- Circular movement characterised by external radius of roundabout D_z, is described in input parameter A_3.

The task relied on such good selection of input parameter values (amplitude A and frequency f), in order to correctly execute the manoeuvre intended to minimise the criterion function J_W. For such a manoeuvre the optimal parameters values found characterising steering wheel input: $A_1 = 3.35$ rad $f_1 = 1.20$ rad/s $A_2 = 3.15$rad, $f_2 = 0.70$rad/s, $A_3 = 2.95$rad. For these criterion function values the minimal value is reached $J_W = 8.15$. Two exemplary simulations were made of a manoeuvre at a speed of 25km/h and external roundabout radius of D_z=50m and R_{wej}=15m and R_{wyj}=16m. Next was conducted a manoeuvre simulation, for these same geometric roundabout parameters, but at a lesser speed - 20km/h and a greater - 30km/h. The following simulation designations were accepted: "1" - simulation results for

D_z=50m and v=25km/h (A_1=3.35rad, f_1=1.20rad/s A_2=3.15rad, f_2= 0.70rad/s, A_3=2.95rad),

"2" - simulation results for D_z=50m and v=25km/h (A_1=3.25rad, f_1=1.20rad/s A_2=3.15rad, f_2= 0.70rad/s, A_3=2.95rad),

"3" - simulation results for D_z=50m and v=20km/h (A_1=3.35rad, f_1=0.90rad/s A_2=3.10rad, f_2= 0.55rad/s, A_3=2.95rad),

"4" - simulation results for D_z=50m and v=30km/h (A_1=3.40rad, f_1=1.55rad/s A_2=3.15rad, f_2= 0.75rad/s, A_3=2.75rad),

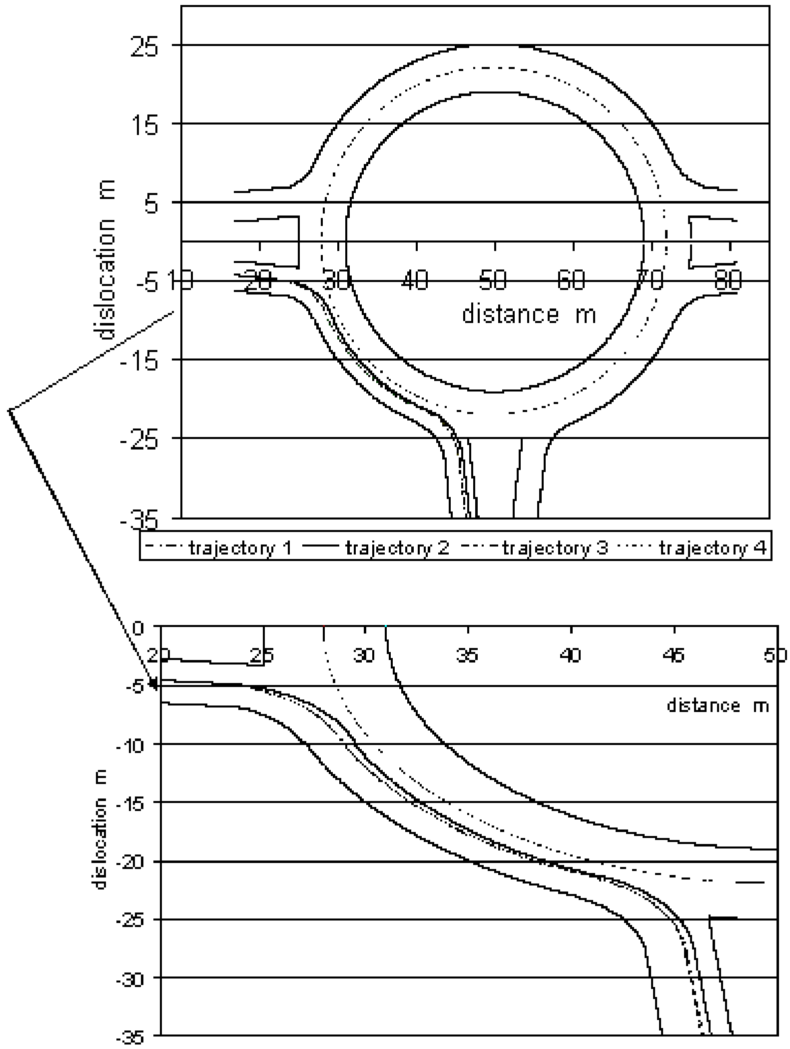

Fig. 8. Movement trajectory for the manoeuvre "¼ roundabout"

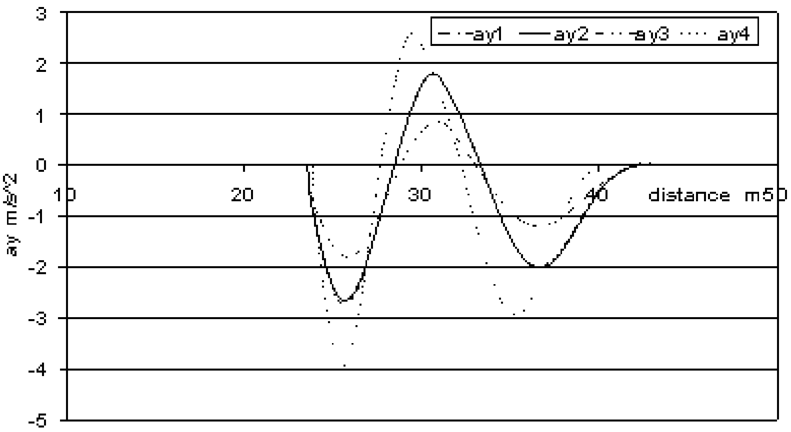

Fig. 9. Lateral acceleration for manoeuvre "¼ roundabout"

In Fig. 7 is presented the steering wheel input ("deltaH"), and in Fig. 8 the movement trajectory. Achieved at such manoeuvre course performance, in Fig. 9 is presented the course of lateral acceleration ("ay"). Value expressions for the presented manoeuvres being criterion function components J_W presented in Table 3. Manoeuvres "1" and "2" were executed during travel at the same speed, with small changes in the type of steering wheel angle input through changes in the amplitude value A_1 of value 0.10rad.

In the light of the criteria, described in point 3, manoeuvre "2" was executed incorrectly, because the permissible travel track width was exceeded. This instance reflects the situation of a "calm" entry to a roundabout, and thus corrects the travel comfort (lateral acceleration criterion). The obtained reduction of a_{ymax} of 0.072m/s^2, (difference in practice not felt by passengers), took place at the cost that the vehicle did not adhere to the designated travel track, and thus the manoeuvre was rejected as incorrect.

Table 4. Matrix of input parameters A and f for manoeuvre overtaking depending on speed v and section length L_p

Lp m \ v km/h	60	70	80	90	100	110	120	130	140	150
250	A=0,15 f=1,20			A=0,15 f=1,75		A=0,15 f=2,05	A=0,15 f=2,20			A=0,20 f=3,05
300	A=0,13 f=1,15	A=0,10 f=1,15	A=0,13 f=1,45				A=0,13 f=2,05	A=0,13 f=2,20		
350					A=0,13 f=1,55		A=0,13 f=2,05		A=0,13 f=2,30	A=0,15 f=2,60
400	A=0,10 f=1,00	A=0,07 f=0,95	A=0,10 f=1,30	A=0,07 f=1,20	A=0,07 f=1,30	A=0,10 f=1,65	A=0,10 f=1,80	A=0,10 f=1,90	A=0,10 f=2,00	A=0,13 f=2,45
450					A=0,07 f=1,30		A=0,10 f=1,80			A=0,10 f=2,15
500							A=0,10 f=1,80			
550				A=0,10 f=1,40			A=0,07 f=1,50			
600	A=0,07 f=0,80		A=0,07 f=1,15	A=0,07 f=1,20			A=0,07 f=1,50	A=0,07 f=1,60		
650	A=0,04 f=0,60	A=0,04 f=0,70	A=0,04 f=0,80			A=0,07 f=1,40	A=0,04 f=1,10		A=0,07 f=1,70	A=0,07 f=1,80
700					A=0,04 f=0,95		A=0,04 f=1,10			

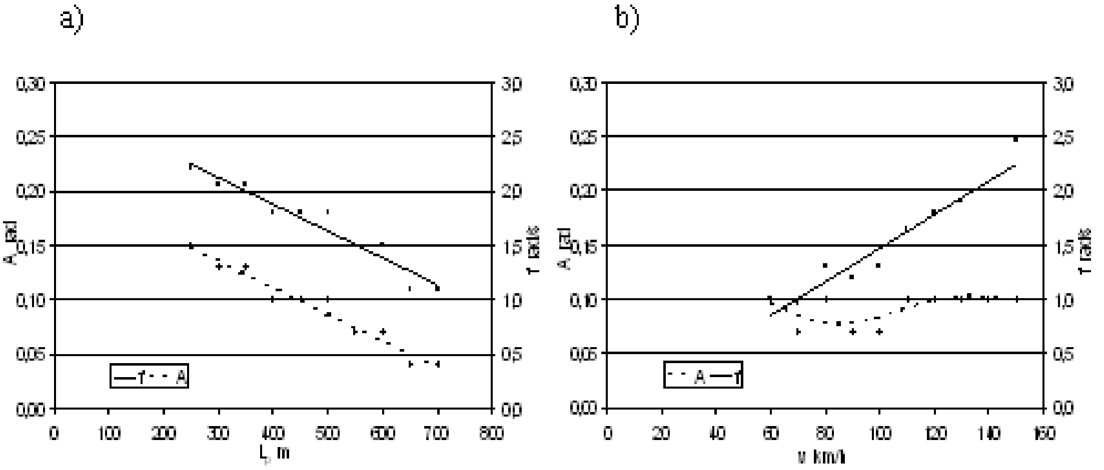

Fig. 10. Course A and f depending on: a) length of straight section L_p, b) travel speed v

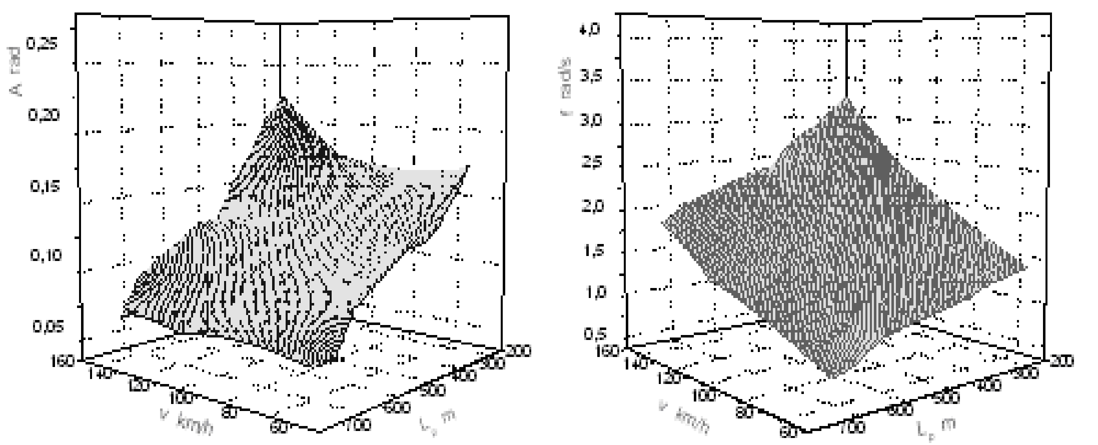

Fig. 11. Dependence of input amplitude A and frequency f on length of straight section L_p and travel speed v

Table 5. Set of input parameter values A1 and f1 depending on external diameter Dz and travel speed v

Dz m \ v km/h	10	15	20	25	30	35	40
25		A_1=4,05 f_1=2,40		A_1=4,10 f_1=2,20			
30	A_1=4,00 f_1=0,75			A_1=4,10 f_1=1,90	A_1=4,15 f_1=4,15		
35		A_1=4,05 f_1=1,20		A_1=4,10 f_1=1,50		A_1=4,20 f_1=3,40	
40	A_1=3,50 f_1=0,55			A_1=3,55 f_1=1,45	A_1=3,60 f_1=2,20	A_1=3,65 f_1=2,20	
45		A_1=3,50 f_1=0,85		A_1=3,55 f_1=1,35		A_1=3,65 f_1=2,00	
50	A_1=3,30 f_1=0,45	A_1=3,30 f_1=0,65	A_1=3,35 f_1=0,90	A_1=3,35 f_1=1,20	A_1=3,40 f_1=1,45	A_1=3,40 f_1=1,65	A_1=3,45 f_1=2,05
55				A_1=3,35 f_1=1,15			
60		A_1=3,30 f_1=0,75	A_1=3,35 f_1=0,90	A_1=3,35 f_1=1,10	A_1=3,40 f_1=1,20	A_1=3,40 f_1=1,35	A_1=3,45 f_1=1,50
65	A_1=3,30 f_1=0,40			A_1=3,35 f_1=1,05			
70		A_1=3,30 f_1=0,60		A_1=3,35 f_1=1,00	A_1=3,40 f_1=1,20		A_1=3,45 f_1=1,75

Table 6. Set of input parameter values A2 and f2 depending on external diameter Dz and travel speed v

Dz m \ v km/h	10	15	20	25	30	35	40
25		A_2=3,75 f_2=0,50		A_2=3,60 f_2=0,85			
30	A_2=3,55 f_2=0,30			A_2=3,60 f_2=0,80	A_2=3,65 f_2=0,95		
35		A_2=3,55 f_2=0,60		A_2=3,60 f_2=0,90		A_2=3,60 f_2=0,90	
40	A_2=3,25 f_2=0,25			A_2=3,35 f_2=0,70	A_2=3,40 f_2=0,85	A_2=3,40 f_2=0,90	
45		A_2=3,30 f_2=0,40		A_2=3,35 f_2=0,65		A_2=3,40 f_2=0,90	
50	A_2=3,00 f_2=0,25	A_2=3,10 f_2=0,45	A_2=3,10 f_2=0,55	A_2=3,15 f_2=0,70	A_2=3,15 f_2=0,75	A_2=3,20 f_2=0,95	A_2=3,25 f_2=1,20
55				A_2=3,15 f_2=0,70			
60		A_2=2,85 f_2=0,30	A_2=2,80 f_2=0,45	A_2=2,85 f_2=0,65	A_2=2,90 f_2=0,80	A_2=2,95 f_2=1,00	A_2=3,00 f_2=1,20
65	A_2=2,85 f_2=0,45			A_2=2,90 f_2=0,80			
70		A_2=2,85 f_2=0,45		A_2=2,90 f_2=0,80	A_2=2,95 f_2=1,15		A_2=3,00 f_2=1,25

This same manoeuvre was executed at lesser and greater travel speeds. Execution of the manoeuvre (“3”) with speed of 20km/h (less by 5km/h in relation to “1” and “2”) caused reduction (in relation to “1”) of lateral acceleration values of over 9m/s^2 (increasing feeling of passenger comfort) and simultaneously reducing the value of component “1/Tintegral” (calm steering). In turn increasing the speed of travel to 30km/h (manoeuvre "4”) caused an increase in value of lateral acceleration of over 30% (Fig. 4) and increase of value of component “1/Tintegral” by approx 25% – Table 3.

In the case of manoeuvre “1” and “2” it may be stated that seemingly small changes in input amplitude values (reduction of A_1 by 0.10rad/s) did not affect improvement of travel comfort - Fig. 9, and caused exceeding of the permissible movement track width.

Meanwhile the seemingly “small” increase of travel speed by 5km/h (manoeuvre “4”) caused a decided deterioration of passenger travel comfort – increase of value “aymax” by 1.23 m/s^2.

Table 7. Set of input parameter values A3 depending on external diameter Dz and travel speed v

Dz m \ v km/h	10	15	20	25	30	35	40
25		A_3=4,95		A_3=4,90			
30	A_3=5,10			A_3=4,75	A_3=5,55		
35		A_3=4,70		A_3=4,30		A_3=5,00	
40	A_3=4,35			A_3=3,65	A_3=4,15	A_3=3,50	
45		A_3=3,35		A_3=3,05		A_3=2,85	
50	A_3=3,40	A_3=3,30	A_3=2,95	A_3=2,95	A_3=2,75	A_3=2,45	A_3=2,45
55				A_3=2,45			
60		A_3=1,95	A_3=1,95	A_3=2,10	A_3=2,10	A_3=2,45	A_3=2,45
65	A_3=1,80			A_3=1,90			
70		A_3=1,75		A_3=1,85	A_3=1,70		A_3=1,70

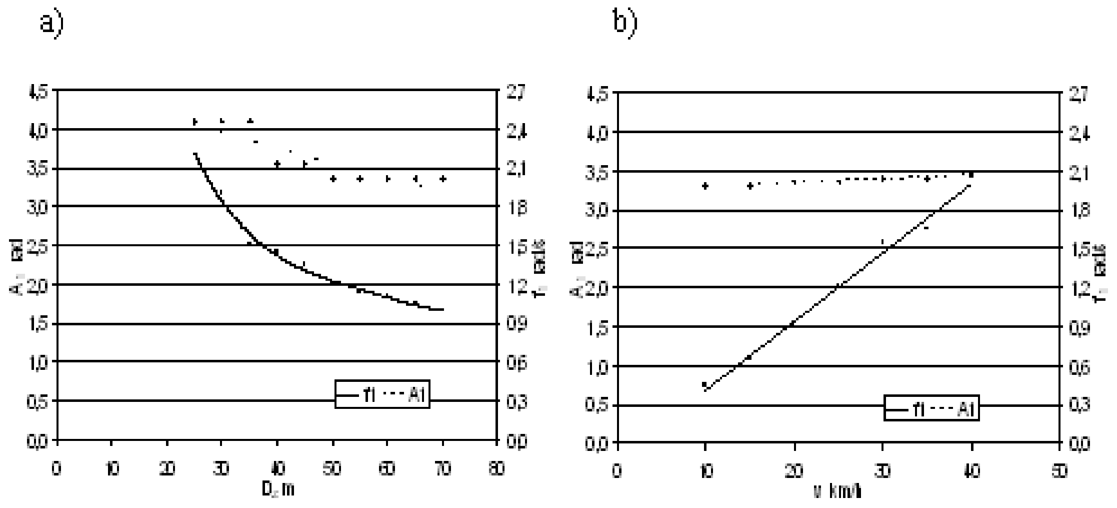

Fig. 12. Course A_1 and f_1 depending on: a) external diameter D_z, b) travel speed v

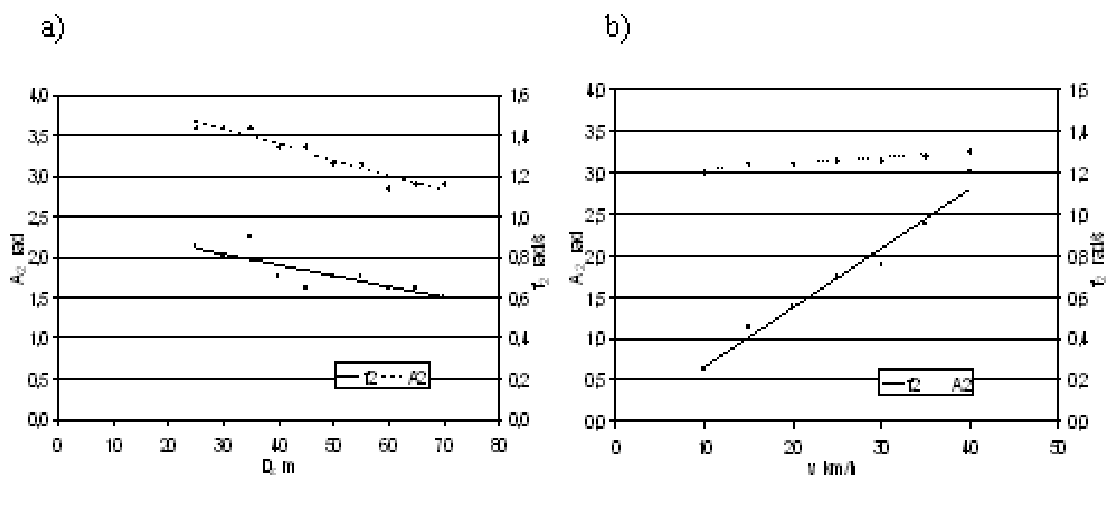

Fig. 13. Course A_2 and f_2 depending on: a) external diameter D_z, b) travel speed v

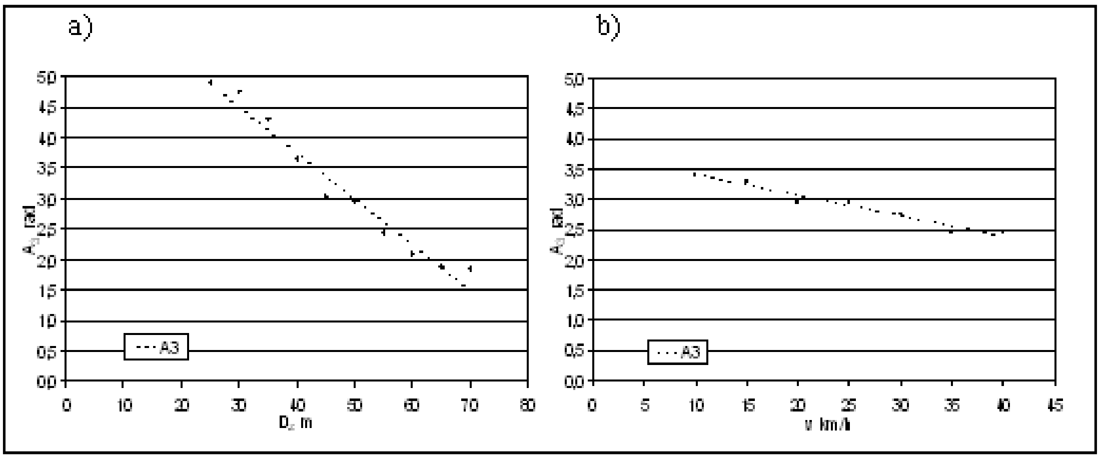

Fig. 14. Course A_3 depending on: a) external diameter D_z, b) travel speed v

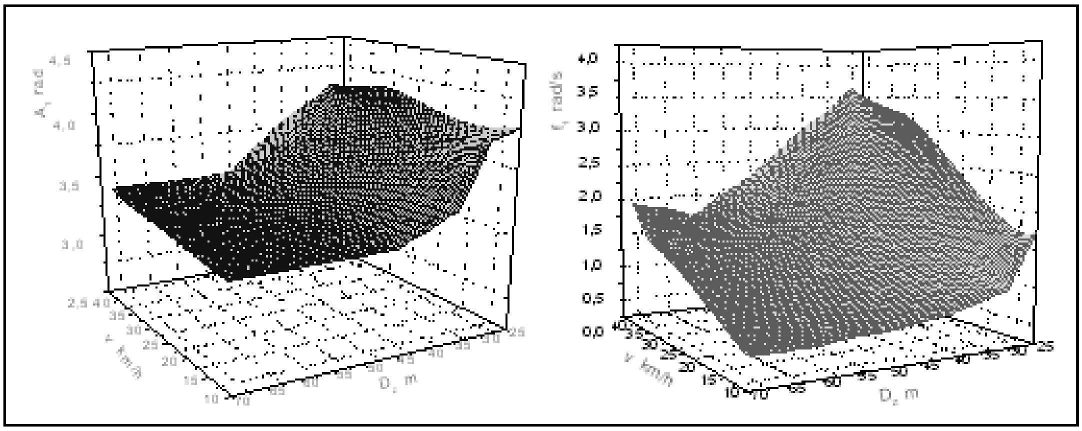

Fig. 15. Dependence of amplitude A_1 and frequency f_1 on external diameter D_z of roundabout and travel speed v

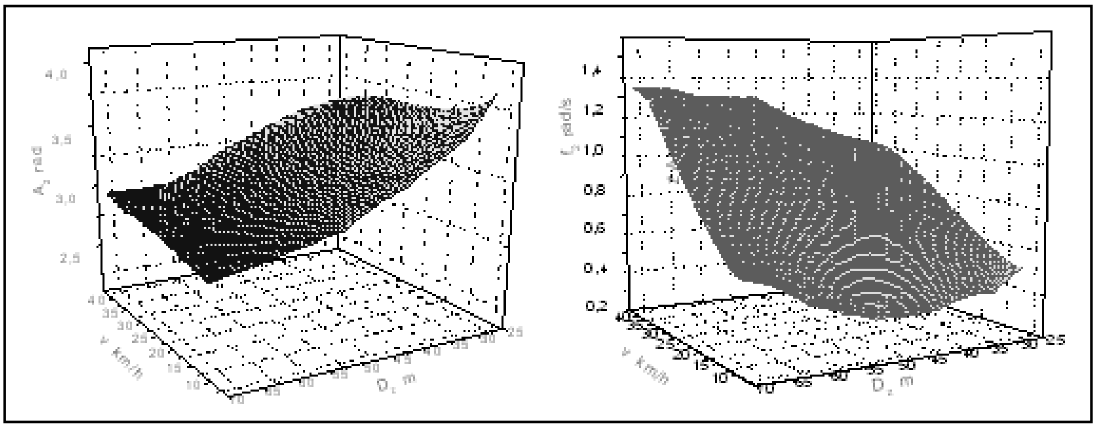

Fig. 16. Dependence of amplitude A_2 and frequency f_2 on external diameter D_z of roundabout and travel speed v

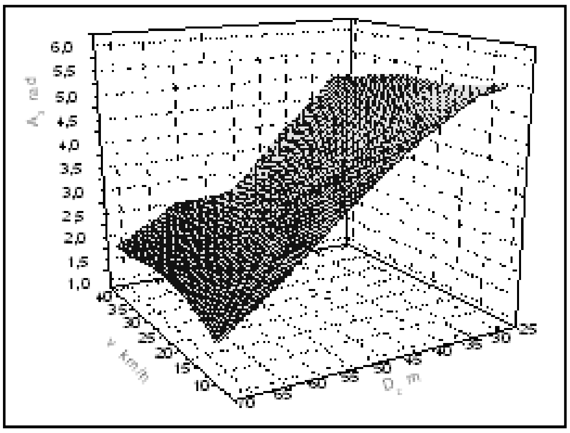

Fig. 17. Dependency of amplitude A_3 on external diameter D_z of roundabout and travel speed v

Optimal input parameters for overtaking manoeuvre and "¼ roundabout

Double change of traffic lane – overtaking: Treating travel speed v and section length L_p (Fig. 2) as parameters characterising overtaking manoeuvre, for various combinations of these parameters, many simulations were conducted seeking the most beneficial (optimal) steering submission input for the performance of this manoeuvre. In Table 4 is shown the outline of the input parameter matrix in the form of sets of A and f parameter values, accepted as optimal for the given manoeuvre depending on travel speed v and section length L_p necessary to perform the manoeuvre. For manoeuvre parameters placed in Table 4, on Fig. 10a and b are shown exemplary courses of input parameters A and f in function of straight section length L_p and travel speed v for chosen instances:

- Straight section length L_p =400m, variable travel speed v,
- Fixed travel speed v=100km/h, variable length of straight section L_p.

In the event change of parameters A and f represented in Fig. 10a and b it may be stated that their values are strongly dependent on the length of straight section L_p, that the driver has during the overtaking manoeuvre. Optimal values equally of amplitude A, as of frequency f are subject to linear reduction together with the increase in length of this section. Whereas the second dependency is interesting as shown in Fig. 10b. It is shown that optimal amplitude input values A have a weak dependence on travel speed, whereas optimal input frequency f increases in linear proximity together with the increase in travel speed. Full illustration of results given in Table 4 constitutes spatial graphs A(v, L_p) and f(v, L_p) shown in Fig. 11. This type of input parameters matrix for the given manoeuvre (Table 4), prepared for the given vehicle, implemented for the curvilinear movement assistance system would be used to choose steering wheel input submission parameters depending on the basic parameters characterising manoeuvre execution conditions.

Simulation results presented in Table 4 constitute significant implementation of the proposed system for the achievement of assisted curvilinear movement in the performance of defined manoeuvres. The system depending on speed and the availability the road section for overtaking manoeuvre, during travel that would use optimal parameters of steering values introduced to the memory system from matrix given in Table 4. Simulations of performed manoeuvres were submitted in the work (Więckowski D., 2006). Travel through medium roundabout – "¼ roundabout" With regard to the correctness of the execution of this manoeuvre in Tables 5, 6 and 7 the input parameter matrix outline is presented in the form of parameters value sets A_1 and f_1, A_2 and f_2 and A_3 accepted as optimal for the given manoeuvre depending on travel speed and external diameter of roundabout D_z. Similar and in this instance of this type of "matrix" prepared for the given vehicle, implemented for the curvilinear movement assistance system that would be used for the choice of input parameters submission to the steering wheel depending on basic parameters characterising the conditions of manoeuvre execution, that is the speed of travel and the external diameter D_z of the roundabout on which the manoeuvre should be executed. Graphic illustration of "matrix" presented in Tables 5 to 7 shown on Fig. correspondingly 12 to 17. For input parameters (A and f) on Fig. 12 to 14 are shown courses of input parameters A and f in external diameter function D_z and travel speed for chosen examples:

- Roundabout with fixed external diameter D_z=50m, variable travel speed v,
- Fixed travel speed v=25km/h, variable external diameter of roundabout D_z.

In the event change of parameters A and f represented in Fig. 12 it may be stated that a strong dependence exists of their course on the external diameter D_z. Where as with reference to the travel speed course parameter A_1 is weakly dependent, and course f_1 shows a strong dependence. In turn or changes of parameters A_2 and f_2 presented in Fig. 13 it may be stated that there is a course proximity of dependence of both these parameters on the external diameter D_z. Whereas with reference to the travel speed course parameter A_2 is weakly dependent, and course f_2 shows a strong dependence. It is a similar situation in the case of parameters A_1 and f_1. For parameter A_3, Fig. 14 it may be stated that a strong dependence exists of the course of this parameter on the external diameter D_z. Whereas with reference to the travel speed course parameter A_3 is less dependent on it. It is interesting that with the increase of travel speed there is a decided increase of the input frequency value f (Fig. 12 and 13), and the amplitude value A is practically fixed (Fig. 12 and 13) or changes are small (Fig. 14). However in the case of growth of external diameter values D_z a decided change occurs (fall) of amplitude value A and frequency f, according to expectations.

Summary

Results of simulation tests confirming the accuracy of search and analysis concept based on the possibility of implementation of the proposed system for the achievement of assisted curvilinear movement with the execution of typical vehicle movement manoeuvres. The system, during travel may use values from appropriate input parameter matrixes (analogous to those presented in the forms of Tables 4 to 7) prepared earlier and introduced to the system, applied them, if the manoeuvre would be executed "incorrectly". Thus the idea may be achieved of eliminating insufficient driver ability, his errors, nonchalance and momentary lack of attention etc. In the majority of published concepts of curvilinear movement assistance systems or "automatic pilot" systems algorithms are used which depend on repetition of the steering loop with a very high frequency of: information - recognition - decision - execution. At each step of this loop, based on information received from appropriate sensors, the situation is analysed, a decision is prepared and an impulse correction is made to the trajeckory (abruptly, with very small movements of the steering wheel). Because all the parameter conversion and the whole situation analysis must be conducted in real time this creates an enormous requirement for calculation power. Therefore the experimental implementation of this type of assistance system is very difficult. The concept proposed creates an incomparably lesser requirement for calculation power. In the presented example simulations of the operation of the steering system loop: information – recognition – decision – execution may be achieved very rapidly due to the input parameters matrix implemented in the system of various types of manoeuvres. The driver perceives the manoeuvre as an entirety and endeavours to execute it according to a certain accepted perception. However during the continuation of the manoeuvre he is obliged to make certain corrections, in which the necessity of making following corrections does not interfere with the general concept of the manner of achieving manoeuvre execution. The presented concept of the operation of an assistance system establishes similar operation, consisting of "perceiving" the manoeuvre as an entirety.

REFERENCES

Busch S. 2005. Entwicklung einer Bewertungsmethodik zur Prognose des Sicherheitsgewinns ausgewählter Fahrerassistenzsysteme, *Fortschritt-Berichte. Reihe 12*: Verkehrstechnik/Fahrzeugtechnik Nr. 588, VDI Verlag, Düsseldorf.

Gerdts M. 2003. A moving horizon technique for the simulation of automobile test-drives. *ZAMM* , vol. 83, No. 3.

Gordon T. J. 2006. On the synthesis of driver inputs for the simulation of closed-loop handling manoeuvres', *Int. J. of Vehicle Design*, Vol. 40, Nos. 1/2/3.

Henning K., Preuschoff E. 2003. Einsatzszenarien für Fahrerassistenzsysteme im Güterverkehr und deren Bewertung. *Fortschritt-Berichte, Reihe 12*: Verkehrstechnik/ Fahrzeugtechnik Nr 581, VDI Verlag, Dusseldorf .

ISO 12021 1994. Cross Wind Behaviour Test.

ISO 12021-1 1996. Road Vehicles - Sensitivity to lateral wind. Open-loop task method using wind generator input.

ISO 3888-1 1999. Passenger cars - Test track for a lane-change manoeuvre. Part 1: Double lane-change.

ISO 4138 1996. Passenger Cars - Steady-state circular driving behaviour - Open-loop test procedure.

ISO 7401 1998. Road Vehicles - Lateral Transient Response Test Methods.

ISO 7975 1996. Road Vehicles - Braking in a Turn - Open Loop Test Procedure.

ISO 9816 1993. Power Off Reaction Test.

ISO TR 3888 1975. 'Road Vehicles - Test Procedure for a Severe Lane – Manoeuvre'.

ISO TR 8725 1998. Road Vehicles - Transient open-loop response test method with one period of sinusoidal input.

ISO TR 8726 1998. Road Vehicles - Transient open-loop response test method with one period of sinusoidal input.

ISO/DIS 3888-2 2000. Passenger cars - Test track for a lane-change manoeuvre. Part 2: Obstacle avoidance.

ISO/DIS 7401 2000. Road Vehicles - Lateral Transient Response Test Methods - Open-Loop Test.

Jürgensohn T., Timpe K.P. 2001. Kraftfahrzeugführung. *Springer-Verlag* Berlin, Heidelberg, New York.

Müller M. (2005). Ein Beitrag zur Entwicklung von Assistenzsystemen für eine vorausschauende Fahrzeugführung im Straßenverkehr. *Doktor Dissertation, Shaker Verlag*, Kaiserslautern.

Pohl. J. Sethsson M., Degerman P., Larsson J. 2006. A semi-automated parallel parking system for passenger cars. *Proc. IMechE. Part D* J. *of Automobile Engineering* Vol. 220.

Stańczyk T.L. 1998. Systemy wspomagania pracy kierowcy (Steering assisted system of drivers)', Z*eszyty Instytutu Pojazdów, nr 3(29) Warsaw University of Technology*, Warszawa (in Poland).

Więckowski D. 2006. Optymalizacja wymuszenia działającego na kierownicę ze względu na kryterium poprawności wykonywania typowych manewrów w ruchu samochodu (Optimalization of steering wheel input function in relation to correct criterion execution of typical vehicle manoeuvers). *Doctor's trial*, The Kielce University of Technology, Kielce 2006. (in Poland).

Wiltschko T. 2004. Sichere information durch infrastrukturgestütze Fahreassistenzsysteme zur Steigerung der Verkehrssicherheit an Straßenknotenpunkten. *Fortschritt-Berichte VDI, Reine 12*: *Verkehrstechnik/Fahrzeugtechnik. Nr 570 VDI Verlag*, Düsseldorf .

Yoshimoto K., Iwatani K., Kokubo T. 1997. Automatic driving using image information. *Technical Notes/JSAE Review 18*.

Yoshimoto K., Obawa H., Kubota H. 1997. Course tracking control algorithm using visual information', *Vehicle System Dynamics 28*.

****