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Assessment of Transport Energy Consumption when Designing Off-Ramps of Flyunder Crossings

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Summary. Dependence between radiuses of curves of off-ramps and transport energy consumption within left- and right-turning directions of traffic of flyunder crossings with the engineering and planning solution of "cloverleaf" type with the help of software system PTV VIS-SIM is investigated. Optimum values, from the point of view of minimization of energy consumption of a transport flow, of their radiuses of curves are defined.

Key words: traffic flow, prediction model, transport energy costs, radiuses of curves, flyunder crossings.

INTRODUCTION

Street and road flyunder crossings with complete and incomplete traffic junctions depending on management of traffic and pedestrians' motion and recommended reference speeds (V_p) at left-turning off-ramps divided into 5 classes [12]. Irrespective of junction class elements of left- and right-turning off-ramps shall be calculated and assigned on the basis of recommended V_p on off-ramps [12]. Choice of V_p within flyunder crossings in each case shall be executed on the basis of detail technical and economic calculations taking into account perspective intensity of traffic in all directions [7].

The existing assessment of planning solutions of crossings is defined by transport and road expenses. Their value, substantially, is defined by radiuses of off-ramps curves, $R = f\ (V_p)$. At the same time, an impact assessment of radiuses of curves on energy consumption of transport flow (TF) as one of the indices of operation of transport is not considered. As within different types of crossings impact of V_p on transport energy consumption is shown unequally, and on the same type of crossing energy consumption of TF changes depending on geometrical parameters of crossing and value of intensity and density of traffic of forward and turning flows, for reasonable acceptance of V_p within flyunder crossings (both on forward and turning directions) it is necessary to conduct detail research. Energy consumption of TF which values can be determined by means of special computer programs shall be one of the criteria for assessment of a choice of V_p. Indeed in the conditions of considerable foreign economic dependence of Ukraine on suppliers of energy carriers (the import share in structure of deliveries of primary types of energy carriers in different years was equal from 53 % to 72% [10] energy saving in transport branch acquires special relevance for general increase of economic efficiency of national economy.

MATERIALS AND METHODS

Optimization of radiuses of curves of off-ramps crossings with engineering and planning solution (EPS) of “cloverleaf” type from the point of view of minimization of transport energy consumption in their limits.

In the world of modern information technologies in planning and analysis of transport systems of cities, implementation of different technical and economic calculations, improving of traffic management and optimization of system of routes of public transport, etc. it is impossible to do without instrument of simulation (simulation modeling) by means of special computer programs. Their use in simulation modeling of TF dynamics considerably simplifies process of its study and control. Instruments allow us to visualize motion of each motor vehicle in the flow, to evaluate the effectiveness of decisions aimed at improving traffic management.

Recently, TF modeling in the transport network of the city is paid much attention. Thus theoretical ideas of TF dynamics develop generally in two directions. On the one hand, micromodels which describe certain specific situations of motion of motor vehicles (MV) in the areas of transport network but which at the same time can't characterize status of TF [4, 9] are considered. On the other hand, there are many macromodels for description of TF dynamics which however aren't intended for analysis of motion of MV on certain specific areas of transport network [3; 5; 8]. Today in the world there are about 30 software products for simulation the most widespread of which are AIMSUN, PARAMICS, IHSDM, Emme/4, MITSIM Transcad, VISSIM, PLANSIM-T, AUTOBAHN, TRANSIMS, DRACULA, SISTM, INTEGRATION, FLEXSYT-II, SimTraffic 6 [1, 6, 17].

In the articles of A.V. Kochetkov, M.M. Bekmahambetov, A.V. Yatskiv, E.A. Yurshchevich., N.V. Kolmakova [1, 19] it is given a comparative assessment of the most widespread software products for simulation modeling on the major criteria for the analysis of transport situations. If to enter indexes for simulation objects and phenomena: weather conditions (1); inspection for parking spaces (2); parked cars (3); specification of engines models (4); commercial cars (5); bicycles and motorcycles (6); pedestrians (7); road traffic accidents (8); public transport (9); measures for stabilizing of flows (10); diffusions of bunching (11); weaving of flows (12); out-of-straight (13), possibilities of software as for their accounting will be marked in the Tab. 1 with symbol X. If to enter the indicators designating the whole simulations according to Tab. 2, possibilities of software as for the accounting of these purposes will be provided similarly in Tab. 3.

As a result, due to ease of use, polyfunctionality, high adaptability, ability to build the most detailed models which are closest to real for further research it is chosen the German model of software family PTV VISION which combines full software package for planning, analysis and traffic management [14].

Table 1. Possibility of objects and phenomena description

Software	1	2	3	4	5	6	7	8	9	10	11	12	13
AIMSUN2	-	-	-	-	-	-	-	*X*	*X*	-	*X*	*X*	*X*
CORSIM	-	*X*	*X*	-	*X*	-	*X*	*X*	*X*	-	*X*	*X*	*X*
DRACULA	*X*	-	-	-	*X*	-	-	*X*	*X*	-	*X*	*X*	*X*
FLEXSYT-II	-	-	-	-	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*
PARAMICS	*X*	*X*	-	-	*X*	-	-	*X*	*X*	*X*	*X*	*X*	*X*
SYSTEM	*X*	-	-	-	*X*	-	-	*X*	-	-	*X*	*X*	-
VISSIM	-	-	*X*	*X*	*X*	-	*X*	*X*	*X*	*X*	*X*	*X*	*X*

Table 2. Simulation purposes

Purpose	Indicator	Purpose	Indicator
Efficiency	*E*1: modal division	Safety	*S*1: headways
	*E*2: motion time		*S*2: overtaking
	*E*3: motion time changes		*S*3: time of the incident
	*E*4: speed		*S*4: number of accidents
	*E*5: bunching		*S*5: speed / incident consequence
	*E*6: frequency of public transport		*S*6: interaction with pedestrians
	*E*7: queue length	Convenience	*F*1: bodily comfort
Environment	*V*1: emissions release		*F*2: stress
	*V*2: level in case of trunk pollution	Technical features	*T*1: fuel consumption
	*V*3 noise level:		*T*2: operation costs

Table 3. Target capability of models

Software	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*E*7	*V*1	*V*2	*V*3	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6	*F*1	*F*2	*T*1	*T*2
AIMSUN2	*X*	*X*	-	*X*	-	-	*X*	*X*	-	-	-	-	-	-	-	-	-	-	*X*	-
CORSIM	-	*X*	*X*	*X*	*X*	-	*X*	*X*	-	-	-	*X*	-	-	-	-	-	-	*X*	-
DRACULA	-	*X*	*X*	-	-	-	-	*X*	-	-	-	-	-	-	-	-	-	-	*X*	-
FLEXSYT-II	-	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	-	*X*	-	-	-	-	*X*	-	-	*X*	-
PARAMICS	-	*X*	*X*	*X*	*X*	*X*	*X*	*X*	-	*X*	*X*	*X*	-	-	-	-	-	-	*X*	-
SYSTEM	-	*X*	*X*	*X*	*X*	-	*X*	-	-	-	*X*	*X*	-	-	-	-	-	-	-	-
VISSIM	*X*	*X*	*X*	*X*	*X*	*X*	*X*	*X*	-	-	*X*	*X*	*X*	-	-	*X*	-	-	*X*	-

Principal components of PTV VISION system are VISEVA module, VISUM and VISSIM models [20]. VISSIM model which allows to model TF motion as on micro- (within separate crossings), and macro- (on the scale of all city) level due to implementation of traffic simulation model is applied to support the solution of the tasks planned by us on optimization of EPS choice of flyunder crossing from the point of view of minimization of expenditure of fuel and energy resources (FER).

Prediction model is constructed on the basis of time intervals, microscopic model in which unit “driver MV” is considered as the smallest unit.

For determination of energy consumption of TF within the projected versions of planning solutions of crossings in the program system PTV Vissim TF motion in their limits is modelled. Thus road conditions which, on the one hand, create TF status, and on the other hand shall conform to requirements of TF for support of the transport utilization properties are considered [11].

TF prediction model considers psychophysiological model of passing after “vehicle ahead” according to Wiedemann by means of implementation of parameters, based on stochastic allocation of TF and considers motion of all MV types: motor-cars, trucks and passenger cars. Allocation of their intensities is established by means of percentage allocation of each type of MV in the general TF. Thus further class division for trucks depending on their loading capacity, for buses – capacity, and for cars – engine displacement is accepted according to standard North American fleet of motor vehicles.

Vissim prediction model enables simulation of TF motion in the most common operation modes of automobile engines in the conditions of city traffic: idling and partial loads [2]. Depending on MV type nature of their motion within the given area of a way will differ. Indeed for each type of MV in Vissim in case of different specific transport situations nature of change of acceleration and braking will be different. In all cases acceleration or braking is a function of actual speed.

One of the factors of transport energy consumption formation is MV loading capacity. As the loading capacity of motor and passenger MV is largely determined by the number of passengers, in case of TF energy consumption assessment within crossings of city trunks (CCT) it is necessary to consider their fullness. Indeed transport energy consumption of the same MV under the same initial conditions, depending on its fullness, will differ. Vissim prediction model allows us to establish average filling coefficient of motor and passenger MV. According to the opinion poll conducted for development of transport model by Kyiv International Institute of Sociology from December, 2014 till March, 2015, by the specialists of JSC "A+C Ukraine" it was found that average filling coefficient of motor-cars for the city of Kyiv is 1,51 which will be accepted for further research. According to own on-site investigations filling coefficient of buses is accepted as 25,0. Thus within prediction model there are no stops of public transport.

Formation of transport energy consumption of trucks doesn't consider their fullness, but it is defined by ratio capacity / weight. In metric units minimum is 7 kW/ton, and maximum is 30kW/ton. Weight of trucks is defined with the help of mass distribution. For each truck Vissim in a random manner selects the appropriate value from the assigned mass distribution and power distribution [18].

Functions offered in Vissim for motor-cars for maximum acceleration approximately correspond to functions in MV model Wiedemann 74. For motor-cars results of the measurements taken before 1974 in Germany were a little optimized due to the restriction set by the user in the field of short temporal steps (Minimum – Maximum). Data for acceleration away were compared to the results of MV testings, received in 2004 within the European research project RoTraNoMo. For trucks curves for acceleration and braking were optimized taking into account data of the European research project CHAUFFEUR 2, 1999. For buses curves correspond to the data provided by transport enterprise of the city of Karlsruhe, 1995. At the same time rated value of acceleration (irrespective of MV type) is optimized depending on value of a gradient on the given area [18]:

- on 0,1 m/sq.s on a gradient percent with a sign "+";
- on –0,1 m/sq.s on a gradient percent with a sign "–".

Frequency distribution function of intended speeds within CCT is especially important parameter influencing throughput of crossing and transport energy consumption in its limits. As intended speed the reference speed regulated by norms (depending on the category of trunk and class of junction) is accepted. Frequency distribution of intended speeds is defined irrespective of MV type.

Entering TFs in prediction model are distributed by the principle of distribution of Poisson. Thus transport energy consumption within all elementary areas of crossings (right- left-turning, swing and forward directions) needs to be calculated separately, changing, thus, priority of passage of a conflict zone (textures and branch rouds) for forward and turning TF. Indeed nature of change of TF energy consumption for each of the given intersection elements the different. At the same time calculation is performed for TF of different intensity, indeed energy consumption of a single MV on a certain area will differ from energy consumption by the same MV as a part of TF in case of a certain mode of motion on the same area. Thus research is carried out in strictly fixed limits of crossing on a dry asphalt concrete covering.

Within turning traffic directions on CCT there are areas of a way (zone of low-speed traffic) where MV driving speed will be lower, than the set reference speed. Within these areas corresponding speed which is valid for this area of a way is set. Herewith MVs, already before the zone of low-speed traffic, automatically reduce the speed and drive with the lower speed in this zone. After its overcoming MVs recover the set reference speed and automatically accelerate.

Calculation of expenditures of FER for any TF is performed by means of standard formulas for values of MV expenditure with TRANSYT 7-CB, program for optimization of temporal signals, as well as data on the value of emission OakRidge National Laboratory US Department of Energy.

RESULTS

Analysis of influence of radiuses of curves of off-ramps on transport energy consumption was checked on flyunder crossings with engineering and planning solution "cloverleaf" type. They should be used on junctions of classes *II*, *III* and *IV* with intensity of left-turning TF less than 15% [12]. In this regard, according to the Tab. 3.3 [12], V_p at left-turning off-ramps is accepted within 15...60 km/h., and on forward directions (according to Tab. 7.1 [13] – 60...80 km/h. Thus, according to the category of trunk, on forward directions it is accepted from 4 to 8 lanes in both directions [13].

On the basis of earlier developed classification of flyunder crossings depending on TF composition, location and assignments [15] data on number of crossings with EPS of "cloverleaf" type in the city of Kyiv for different groups of crossings are given (Tab. 4).

For each of the given groups of crossings full-scale survey are conducted to determine the parameters of TF within its limits. Because combined groups of crossings have similar, to some major groups of crossings, structure of TF, for implementation of further research we will integrate them:

- On the approaches to the city – with railway lines → on approaches to the city;
- In the central zone of the city – with railway lines → in the central zone of the city
- Bridge-crossings – with railway lines → bridge-crossings.

So, typical for specific group of crossings structure of TF is given in Tab. 5.

In case of identical characteristics of entrance TF the change of percentage distribution of TF by the directions causes the change of index of transport energy consumption within crossing. However in this research for all prediction cases we accept the following percentage distribution of TF:

- 67% – forward TF;
- 15%: – left- and right-turning TFs;
- 3% – swing TF.

Radius of curvature and gradient are set as key parameters of impact on TF energy consumption on the turning directions. Thus the speed of the curvilinear motion of a car is accepted as constant throughout the whole turn. When reviewing all path of motion of

Table 4. Distribution of crossings with EPS of "cloverleaf" type on groups

Group of crossings	Number, pcs.
On the approaches to the city	5
with railway lines	2
In the central zone of the city	3
Bridge-crossings	1
Other crossings	7
Integrated	
On the approaches to the city – with railway lines	1
In the central zone of the city – with railway lines	3
Bridge-crossings – with railway lines	2
Total	24

Table 5. Structure of TF

Group of crossings	Intensity, %		
	Motor-cars	Trucks	Passenger vehicle
On the approaches to the city	73,2	23,0	3,8
With railway lines	78,6	9,3	12,1
In the central zone of the city	84,0	3,0	13,0
Bridge-crossings	75,0	15,8	9,2
Other crossings	77,0	12,4	10,6

MV on the given direction it is necessary to consider transport energy consumption both on entry point, and pulling-out from off-ramps. At the same time change of a gradient on the turning directions in case of adjustment of radiuses of off-ramps wasn't considered.

During the research of flyunder crossings with EPS of "cloverleaf" type it was defined transport energy consumption within crossings depending on radiuses of left-turning off-ramps ($R = f(V_p)$). Radiuses of horizontal curves (R), depending on the accepted V_p at off-ramps, are accepted in compliance with Tab. 6 [12].

Calculation is performed for right- and left-turning TF in case of different prediction intensities within crossings, indeed the mode of motion is one of the factors influencing transport energy consumption [16]. Research is carried out for cases, when summary intensity of TF ($N_{sum.}$) within crossing exceeds 6000cars/hour that conforms to normative requirements necessarily for arrangement of flyunder crossings [12] and doesn't exceed maximum intensity of TF (11000 cars/hour) that leads to formation of bunchings and long stops in case of the given structure of TF. In this regard some variants of crossings with EPS of "cloverleaf" type with V_p on turning and forward directions which conform to requirements of State Construction Standards B.2.3-5-2001 are designed and analysed for this purpose.

Table 6. Radiuses of curves

V_p, km/h	R, m
15	15
20	15
30	35
40	65
50	110
60	160

Nature of change of transport energy consumption for the left-turning motion directions when $N_{sum.}$ = 6000 cars/hour, intensities of incoming flow ($N_{inc.}$) 1500 cars/hour and variable structure of TF, V_p = 60 km/h and 4 lanes in a forward direction (by provision of priority of motion to forward TF), is provided on Fig. 1.

Nature of change of transport energy consumption for the left-turning motion directions when $N_{sum.}$= 11000 cars/hour, $N_{inc.}$= 4000 cars/hour and variable structure of TF, V_p = 60 km/h and 4 lanes in a forward direction (by provision of priority of motion to forward TF), is provided on Fig. 2.

At right-turning off-ramps, proceeding from conditions of motion safety, V_p shan't exceed 60 km/h and should be most approached to the speed on forward directions [12]. In this regard transport energy consumption on the right-turning motion directions in case of different radiuses of border crossings and branch roads of right-turning off-ramps which correspond to the range of reference speeds within 30...60 km/h and steady radius of left-turning off-ramps was defined (R = 35 m). Nature of change of transport energy consumption for the right-turning motion directions when $N_{sum.}$= 6000 cars/hour, $N_{inc.}$= 1500cars/hour and variable structure of TF, V_p = 60km/h and 4 lanes in a

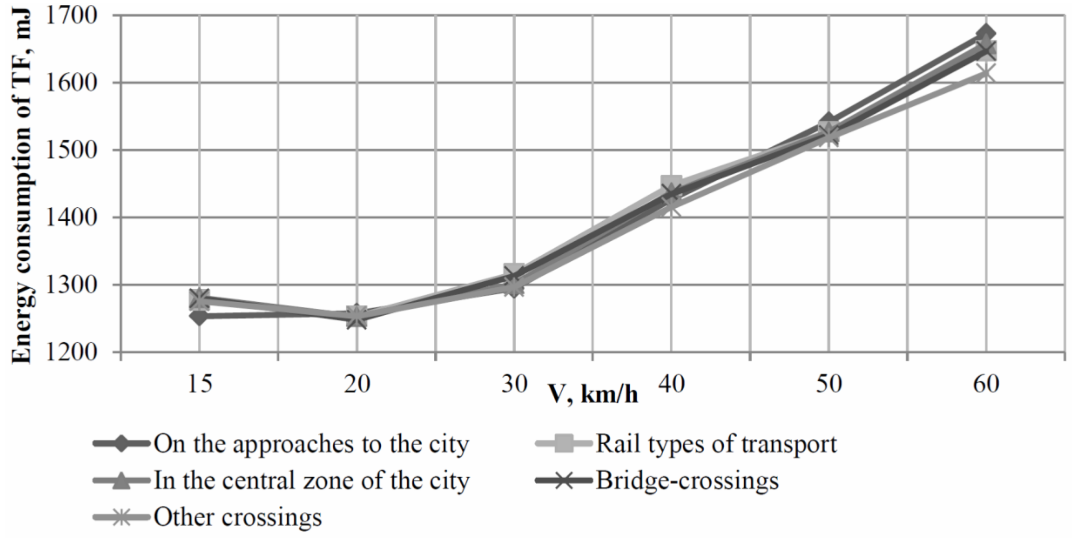

Fig. 1. Nature of change of TF energy consumption in the left-turning direction when $N_{sum.}$ = 6000 cars/hour

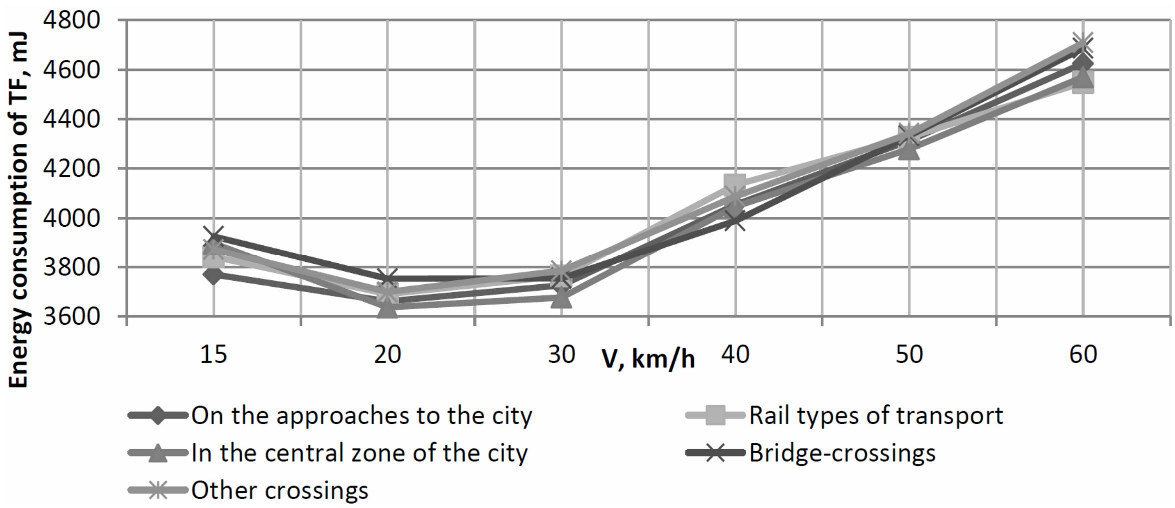

Fig. 2. Nature of change of TF energy consumption in the left-turning direction when N_{sum} = 11000 cars/hour

forward direction (by provision of priority of motion to forward TF), is provided on Fig. 3.

At right-turning off-ramps, proceeding from conditions of motion safety, V_p shan't exceed 60 km/h and should be most approached to the speed on forward directions [12]. In this regard transport energy consumption on the right-turning motion directions in case of different radiuses of border crossings and branch roads of right-turning off-ramps which correspond to the range of reference speeds within 30...60 km/h and steady radius of left-turning off-ramps was defined (R = 35 m).

Nature of change of transport energy consumption for the right-turning motion directions when $N_{sum.}$ = 6000 cars/hour, $N_{inc.}$ = 1500cars/hour and variable structure of TF, V_p = 60 km/h and 4 lanes in a forward direction (by provision of priority of motion to forward TF), is provided on Fig. 4.

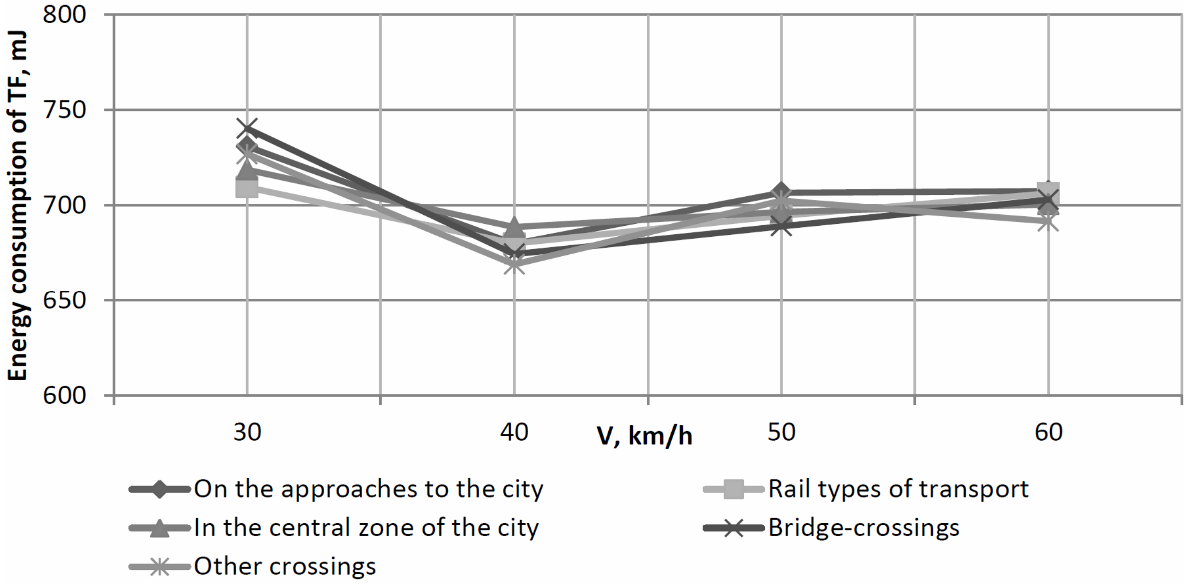

Fig. 3. Nature of change of TF energy consumption in the right-turning direction when $N_{sum.}$ = 6000 cars/hour

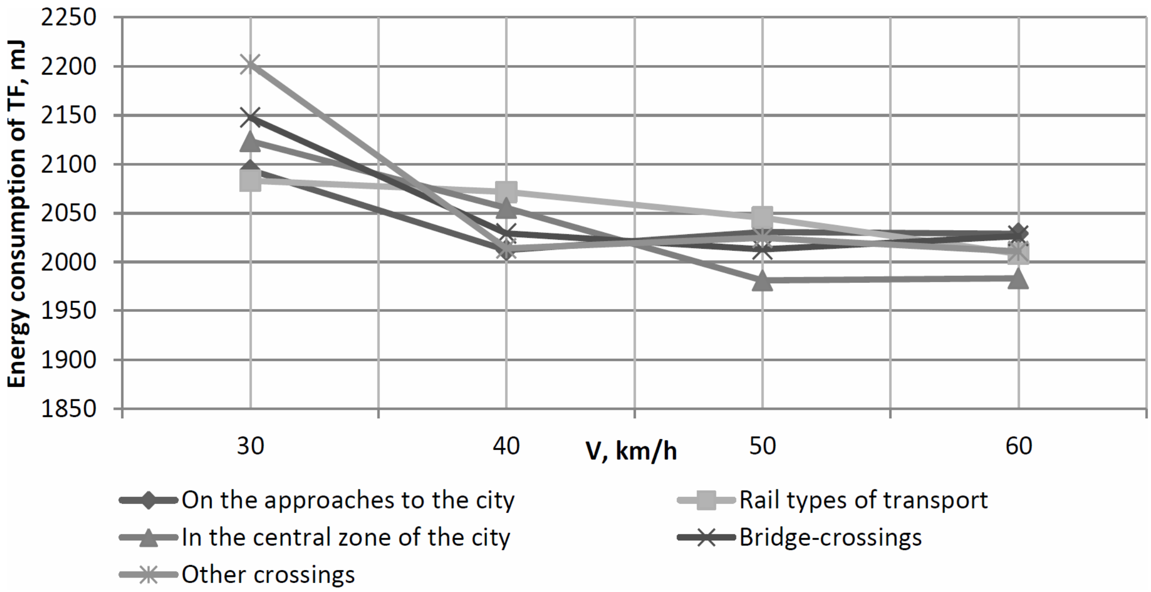

Fig. 4. Nature of change of TF energy consumption in the right-turning direction when $N_{sum.}$ = 11000 cars/hour

CONCLUSIONS

In the analysis of results of TF energy consumption research under the given minimum ($N_{sum.}$ = 6000 cars/hour), maximum ($N_{sum.}$ = 11000 cars/hour), as well as intermediate ($N_{sum.}$ = 7000 cars/hour, $N_{sum.}$ = 8000cars/hour, $N_{sum.}$ = 9000 cars/hour, and $N_{sum.}$ = 10000 cars/hour) intensities of TF it is established that TF energy consumption of the turning directions is influenced by radiuses of curves of off-ramps. It is established that the smallest transport energy consumption (for all groups of crossings) arises under radiuses of left-turning off-ramps 15m and V_p = 20 km/h. Thus the structure of TF doesn't influence nature of distribution of TF energy consumption. At the same time, with growth of $N_{sum.}$ the range of change of indices of TF energy consumption grows both in the left-turning, and in the right-turning directions. Within right-turning off-ramps (with growth of $N_{sum.}$) directly proportional linear dependence of TF energy consumption reducing from increasing in radiuses of curves of right-turning off-ramps is seen, that is the characteristic for all groups of crossings. As a result, optimum (on the index of transport energy consumption) the radius of right-turning crossings, depending on $N_{sum.}$, ranges within 65...160 m and doesn't depend on structure of TF.

One of selection criteria of the engineering and planning solution of flyunder crossing are technical and economic indices (transport, road, given expenses, etc.). However, today, among the existing evaluation indices there is no transport energy consumption. On the basis of the conducted research it is established that TF energy consumption in the left- and right-turning directions is defined by radiuses of curves of off-ramps and by the extent of TF. As far as specified parameters, except for transport energy consumption, influence the other technical and economic indices, for an objective assessment of the planning solution of crossing by the separate evaluation criterion should appear TF energy consumption.

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ОЦЕНКА ТРАНСПОРТНЫХ ЭНЕРГОЗАТРАТ ПРИ ПРОЕКТИРОВАНИИ СЪЕЗДОВ ПЕРЕСЕЧЕНИЙ В РАЗНЫХ УРОВНЯХ

Аннотация. Исследована зависимость между радиусами кривых съездов и транспортными энергозатратами в пределах лево- и правоповоротных направлений движения пересечений в разных уровнях с инженерно-планировочным решением типа «клеверный лист» с помощью программного комплекса PTV VISSIM. Определены оптимальные, с точки зрения минимизации энергозатрат транспортного потока, показатели их радиусов кривых.

Ключевые слова: транспортный поток, расчетная модель, транспортные энергозатраты, радиусы кривых, пересечения в разных уровнях.