SIMULATION OF CITY BUS OPERATION PROCESSES AS TRANSPORTATION SYSTEM REALIZATION

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ABSTRACT

In the paper methods of modelling nonlinear transportation systems have been presented basing on urban buses in aspect of considering processes connected with city-logistics. In chapter 1 deterministic nonlinear model of functioning of urban traffic transportation system has been formulated with distinction of elements dependent on vehicle operating systems. In the next chapter has been presented test method as well as investigations carried out together with the results obtained for the NEOPLAN N4020 bus. The investigations were carried out in Warsaw.

1. NON-LINEAR MODEL OF URBAN TRAFFIC TRANSPORTATION SYSTEM FUNCTIONING.

In the assumed model of the transportation system we assumed one type of decision variables, two types of restricting conditions and six types of criteria. Decision variable in the model is traffic frequency in a given traffic line h (ω_h). The total number of decision variables occurring in the assumed model depends on number of traffic lines in the analyzed transportation system and equals H. All types of restricting conditions, which occur in the model, have of course a determining character and each of them is analysed for the particular traffic lines conditions. The total number of restricting conditions equals thus 2H. The first Group of restricting conditions defines permissible values of traffic frequency in the particular communication lines according to relation $60/i_6 \le \omega_h \le 60/i_0$

The following types of criteria were taken into consideration:

1) traffic interval IR_h
2) waiting time CO_h
3) bus change factor WP
4) overcrowding degree SP_h
5) running costs KE
6) effectiveness EF_h

In addition we calculated in the model III:

1) operating speed PE_h
2) number of vehicles x_h

From all of six types of criteria two of them WP and KE have a global character, that means that they are defined as general indicators for the whole urban traffic system.. The other four IR_h , CO_h , SP_h and EF_h have been analyzed in the particular traffic lines. Therefore the total number of criteria amounts to 4H+2. Criteria 1) and 6) are maximized and criteria 2) ÷ 5) are minimized. The criterion traffic interval (IR_h) is defined (in minutes) in the form of:

$$IR_h=60p_mS_h/(P_hS_{sr}) \quad (1)$$

where:

p_m - vehicles capacity (in person),

S_h - length of communication line,

P_{hr} - the number of passengers by the line,

Ssr - average length of personl trip (km).

Thin criterion is maximized and number equals is H.

The criterion of waiting time (CO_h) is often formulated partially in a nonlinear function with use of an approximation with a multinomial of the sixth degree. The successive criterion, which is taken into consideration in nonlinear models, is the factor of changes (WP). This is one of the two global criteria. As a minimized criterion it belongs to a group of criteria, which are essential for a passenger, it is determined on base of the equation

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$$WP^{(h)}=d_2CO_h^{\,2}+d_1CO_h+d_0 \quad (2)$$

where d_0 , d_1 and d_2 are constants determined for the specified traffic conditions.

The relation 2 will, after simple transformations, assume a form:

$$WP=\frac{1}{H}\sum_{h=1}^{H}[d_2(b_6w_h^6+b_5w_h^5+...+b_1w_h+b_0)+d_1(b_6w_h^6+b_5w_h^5+...+b_1w_h+b_0)+d_0] \quad (3)$$

The successive criterion considered in the non-linear model is the overcrowding degree (SP_h) in a given traffic line in form of:

$$SP_h=P_{hmax}/(p_m\varpi_h) \quad (4)$$

where: Ph_{max} – max. passengers flow,

p_m - vehicles capacity (in person),

ϖ_h - traffic frequency.

Thin criterion is minimized and hence it is of great importance for a passenger. It is analyzed for each traffic line h.

Last but one from criteria running costs is a global criterion belonging to a group, which is essential one from the point of view of a transportation firm. This is a criterion, which as a minimized one tends to reduce general outlays spent. to secure functioning of urban communication syste33m. This system is determined as:

$$KE=\sum_{m=`1}^{L} z_m n_{wkmm} \quad (5)$$

where: KE – Total running cost of functioning of the communication system.

Each of the magnitudes occurring in the formula (5), ie. Z_m i n_{wkmm} has been modelled in a different way. With reference to the cost of a bus-workday we assumed to calculate it according to an equation

$$z_a=g_{lt}PE^{g2q}{}_h+g_{3a} \quad (6)$$

The operation speed PEh, occurring in Thin relation can be calculated from the equation

$$PE_h=60S_h/(t_h+\Delta_h) \quad (7)$$

where:

PE_h - ooperational speed,

S_h - length of communication line,

t_h ,Δ_h - time of trip and parking.

The operation speed of a transportation unit of m type operating in h communication line is not a criterion of thin model as it is independent from the decision variable. Thin magnitude calculated according to the equation (7) is provided to the decision maker as an additional effectiveness indicator which is essential from the point of view of the user as well as the operator of a communication system. After some transformations the cost of one bus-kilometre can be determined from the equation

$$z_a=g_{1a}(60S_h/(t_h+\Delta_h))^{g2a}+g_{3a}$$

$$dla\ v_{1a}\leq(60S_h/\ /(t_h+\Delta_h))\leq v_{3a} \quad (8)$$

and the number of bus-kilometres can be presented in form of::

$$n_{wkmm}=\sum_{k=k_{m-1}+1}^{k_{m-1}+k_m}(60\,\alpha x_h S_h\,/(t_h+\Delta_h)),$$

$$m=1,2,\ldots,L \quad (9)$$

After further (simple) transformations we will obtain

$$n_{wkmm}=\sum_{k=k_{m-1}+1}^{k_{m-1}+k_m}(60\,\alpha S_h\omega_h),$$

$$m=1,2,\ldots,L \quad (10)$$

ϖh - traffic frequency

Hence the final form of the criterion of operation costs will assume a form of:

$$KE=\sum_{h=1}^{H}2\alpha S_h(f_1(60S_h/(t_h+\Delta_h))^{f2}+f_3)\omega_h \quad (11)$$

where f_1, f_2,f_3 non-linear coefficients.

In effect a linear dependence of operation costs on traffic frequency has Bern obtained.

There is, however, some nonlinearity in thin equation connected with the cost of bus-kilometre, though they are directly invisible. The last criterion –effectiveness (EF_h) – is a quotient of number of passenger-kilometres and number of bus-kilometres in a given communication line.

$$EF_h = D_h / n_{wkmm} \quad (12)$$

Schedule speed and number of buses x_h assigned to a communication line h are provided to a decision maker as indicators aiding the analysis and the decision makes process.

2. SIMULATION OF RUNNING PROCESSES – DEFINING THE RUNNING (SCHEDULE) SPEED.

For simulation of running processes a computer system was created, the BASIC part of which is the data base in which are gathered the so called model signals for running vehicle processes under specific urban conditions.

Fig.1 Investigated bus NEOPLAN N4020

The investigations were carried out on a low-floor bus NEOPLAN N4020 (Fig. 1) which the specification is presented in table below.

DIMENSIONS	
Length	14 600 mm
Width	2 500 mm
Height	2 950 mm
Wheel space	7 000 mm
WEIGHTS	
Complete vehicle weight	13 800 kg
Permissible weight	25 000 kg
ENGINE	
Type	DAF GS 200M, lying
Power	200 kW
Max revolutions	2 300 revs/min
Max. torque	1010 Nm at 1500 revs/min

During the investigations the total weight of the bus amounted:

- 12 tonnes of cargo plus bus weight equal 13,8 t plus driver, three persons to make measurements and weight of the measuring equipment.
- 6 tonnes of cargo plus bus weight equal 13,8 t plus driver, three persons to make measurements and the weight of the measuring equipment.

The following sensors were used to make measurements:

Extensometric torque meter with a digital telemetric signal transmission, sensors to measure rotational speed of wheels provided with optoelectronic rotational converters MOL2500, sensor of longitudinal and transverse speed V-1 of DATRON mounted at the rear of the bus, which is presented in the drawing.

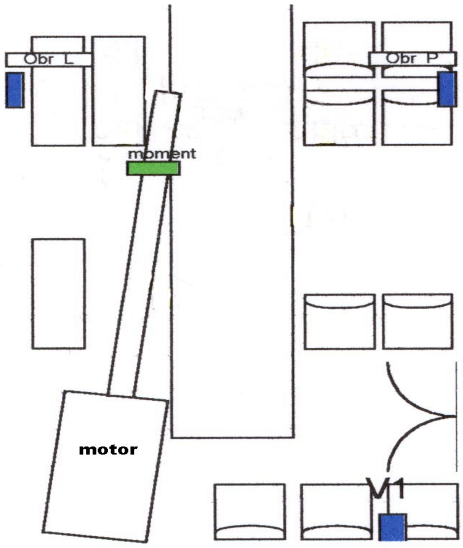

Fig. 2 Arrangement of sensors at the rear of the bus

Parameters of sensors used are provided in the table below.

OPTIC SENSORS V1	
Range of measurement speed-V1	0,25...310 km/h
Measurement terror	± 0,5 % in measu-rement INTERNAL
Outlet frequency	0 - 40 kHz
Digital outlets (RS 485)	3 - Vx, Vy, direction Vy
SENSORS OF ROTATIONAL SPEED OF WHEELS	
Type	MOL2500
Measurement range	4, 8, 16 i 32 revs/s
Resolution (number of graduations)	2500
Output signal	Analogue ±5 V

All sensors co-operated with a digital data acquisition unit of German DATRON – AEP 2.50 of resolution of 12 bits with a portable computer.

The investigations were carried out on 18-21 June 2001 in Warsaw on routes proposed by Urban Bus Company.

In the drawing 38 a map of investigation routes is presented. General investigations were carried out in two stages:

for traffic jams during morning rush hours for 50 % bus load,

for traffic jams during afternoon rush hours for 100 % bus load.

Fig. 3 Map of a ride along investigated routes

During the measurement the most characteristic bus operation periods in DRIVE in urban traffic were measured:

Rides in a street „jam" – starting and stopping a bus in result of traffic of a vehicle stream,

Rides along routes of urban bus lines – starting from bus bays with joining the intense urban traffic and pulling over into a bay with pulling up at bus stops,

Rides along routes in the streets of deteriorated surface conditions – uneven asphalt surfaces and surface of concrete slabs/tiles,

Average rides beyond rush hours through streets of city centre.

After having done investigations on chosen street sections in Warsaw modelling the ride along routes was started with consideration to the below given requirements:

It was assumed (on base of measurements), that there are two types of road slopes which amounted to 1% i 2%. Hence a test schedule has been defined on each ride through a given city bus route so that a bus drives 80% on flat roads and 10% -on 2% ascending roads.

It was assumed (basing on measurements carried out by MZA-Warszawa), that in rush hours (7-11 and 16-19) the bus load amounts to 100% (and most often to 125%), while beyond the rush hours it equals 50% only. According to European standards the load should be related to percent schedule of the ridden road and thus:

% LOADS	% OF A RIDDEN ROAD
0-50	60
50-75	25
75-100	10
100-125	5

But the Warsaw criterion refers to the time of implementation of a ride process which seems to be a more correct interpretation from the point of view of stream of people observed. Comparison of the both criteria (in percentage) allows to state that the Warsaw criterion is more „rigorous" in relation to the European one in aspect of bus load amounting to 125%;

Two types of bus stops were assumed; bus bay and start from a bus stop located directly on a road;

On base of the investigations it was found that about 50% of distances between the bus stops is being taken by start/stop process and the other 50% takes the ride. This is anyhow a non-rigorous criterion, as at small distances between the bus stops (500 m) a start/stop process was basically observed on the whole section of the ride;

Types of surface (normal, moguls tram tracks, cobblestones and narrow streets);

Types of traffic: relatively smooth traffic, traffic with non-numerous bus stops and traffic with numerous bus stops during rush hours.

Such formulated requirements have been implemented during a drive simulation process in an 8 hours workday with consideration made that a stop at a bus stop equals 15 sec. (for a 50% load) and 30 sec (for an 100% load), which results from measurements made by MZA-Warszawa. Moreover a 15 minutes long breakfast break is proposed. In the simulation process a process of driving from the bus depot to a ride route as well as driving from the route to bus depot after finished work have also been taken into account..

Routes Nos: 189, 172, 157 and 517 were taken for simulation.

Exemplary results for the assumed drive hours from 6:30 till14:30 for the route 157 were presented in form of diagrams:

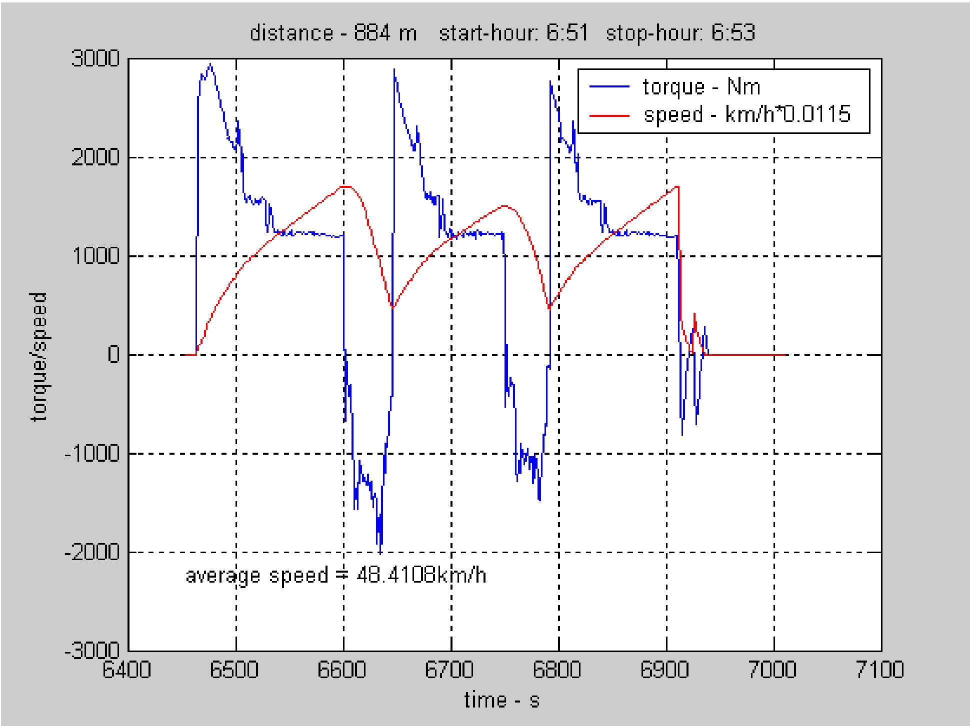

Fig. 4 Street traffic of small intensity

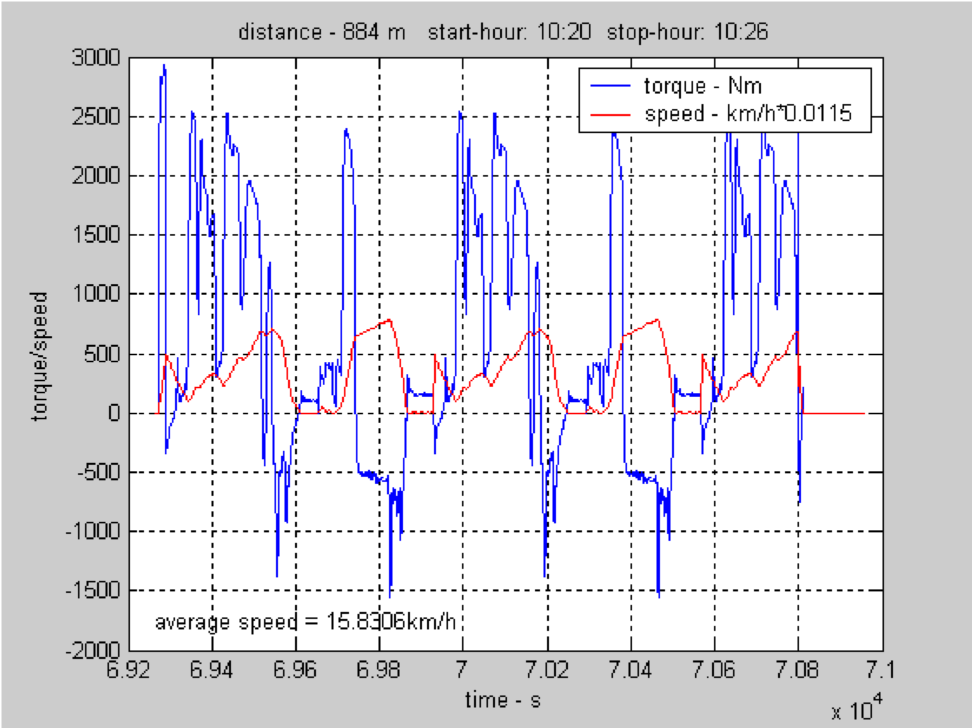

Fig.5 Street traffic of high intensity

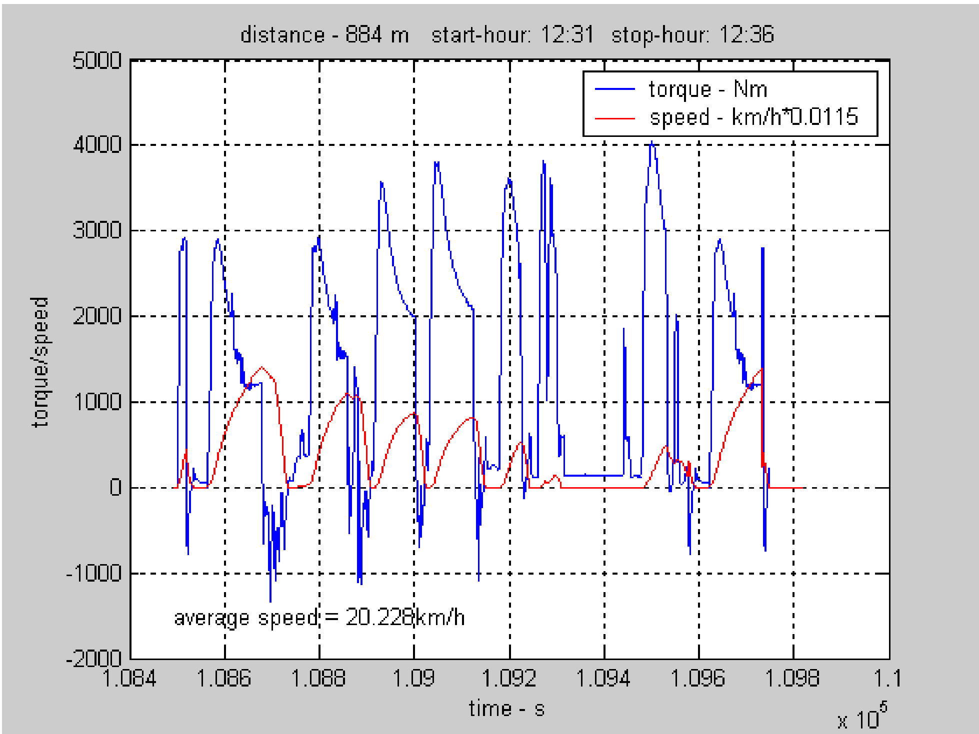

Fig. 6 Street traffic of medium intensity

It results from the diagrams shown in Fig. 4 - Fig. 6 That on the same section of the chosen route the average (medium) speed changes much in function of hours of drive implementation.. Much more important significance in fuel consumption has a torque which increases non-linearity at the stop&go drive. Hence it results that average running cost of a bus is a function of two variables that is the route of a specific road section as well as time of implementation of the drive.

Operational cost of this road section in function of time has been presented in fig.

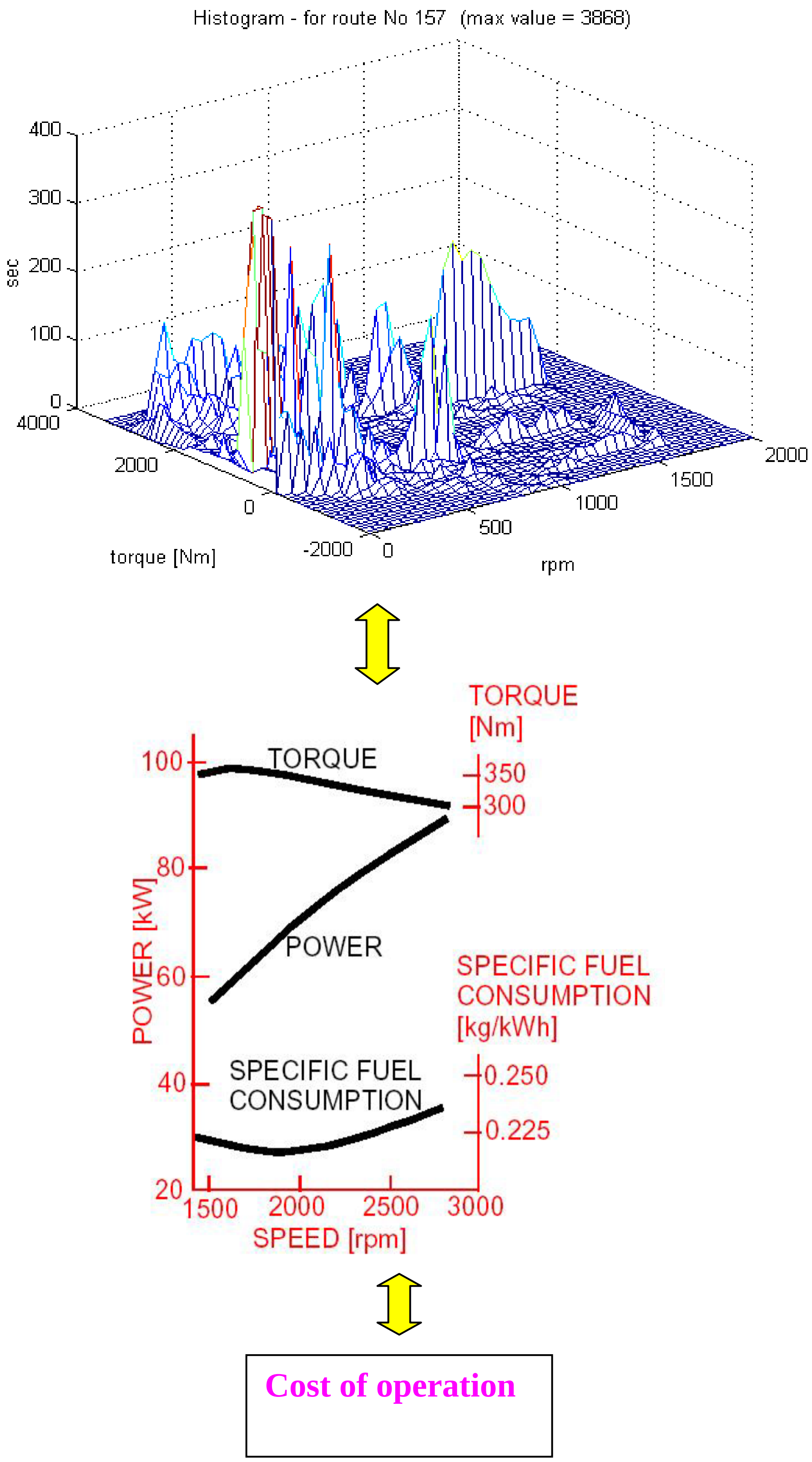

Fig. 7 Histogram of loads obtained for route 157 with operation cost of a bus in function of work time

3. CONCLUSIONS

On base of the analysis carried out of the processes occurring in buses operated the running costs should be assumed for modelling transportation systems in aspect of their optimization as a function of two variables – road and work time, which is directly connected with the traffic intensity.

REFERENCES

Bouzaiene-Ayari, B.; M. Dror, G. Laporte. "Vehicle Routing with stochastic demands and split deliveries. Fundation of Computing and Decision Sciences, 1993, vol. 18, No.2, 63-69.

Osmólski, W.; S. Krzyżaniak. „Simulation Research Methods In First Joint Conference of International Simulation Societies", Zurich, 1994, 525-529.

Bielli M.; G. Improta. „Integration of operations research and artifical intelligence for Urban traffic control and management. Proc. Of 6 WCTR (Abstracts), Lyon, 1992, No 858.

Saxena, P.K. "Lexicographic bi-criteria transportation problem with additional testrictions. Proceedings of 10 International Conference on MCDM, Taipei, 1992, vol. IV, 241-249.

Willumsen, L.,G. Simplified Transport Models based on Traffic Counts, Transportation 10, 257-278.

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WALDEMAR OSMÓLSKI was born in Poznań, Poland and went to the Technical University of Poznań, where he studied cars and vehicles construction and obtained his degree in 1988. He worked for Transmeble SCANSPED Sp. z o. o. (Swedish carriage and forwarding company) as logistics and development manager, then in Raben Transport Sp. z o. o. (Dutch carriage and forwarding company) as dispatcher , selling and administration manager and from 1-st December 1996 till today - managing director, Ponetex Logistics and Customs Agency Sp. z o.o. (Dutch logistic company).

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