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Improving financial conditions of ATEs in the city of Dnipro basing upon optimal assignment of vehicle fleet to the routes

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Abstract: Topicality of the problem solution concerning optimal assignment of vehicles to municipal routes for auto-transport enterprises (ATE) in the city of Dnipro has been substantiated. Technological and economic evaluation of DATP 11255 PJSC activity has been represented. An overview of the available models to assign buses to routes with the determination of their sphere of use has been given; key advantages and disadvantages have been specified. Structure of the model for optimal assignment of buses to the routes have been proposed where target function is represented by maximization of ATE income, and the restriction is represented by non-exceedance of maximum admissible values of traffic interval and coefficients of bus capacity use. Passenger flow in terms of DATP 11255 PJSC routes during morning rush hour has been studied by means of table method. Basic technical-operational and economic parameters of the operation of DATP 11255 PJSC routes have been evaluated. Microsoft Excel SOLVER add-in has been applied to obtain optimal assignment of bus departures which will make it possible to do the following: to increase DATP 11255 PJSC income by 2.62 times (from 462.8 UAH/hour up to 1 211.8 UAH/hour); to improve quality of transportation process owing to the reduced maximum coefficient of the bus capacity use; and to ensure non-exceedance of maximum admissible bus traffic interval.

Keywords: target function, restriction system, optimal assignment, prime cost.

1. Introduction

Public municipal passenger transport (PMPT) is a complex multilevel system which studying requires using methods of system analysis; the methods include complex research of PMPT functioning problems and development of efficient tools for its improvement [1].

Despite certain budgetary support, under the conditions of financial crisis, being observed in the country, efficiency of PMPT operation in cities and towns is still low. Lack of funds to renovate (maintain) the vehicle fleet, random formation of route network, considerable uncontrolled competitiveness among official and illegal transporters result in unprofitability or weak profitability of the majority of ATEs, including ATEs in the city of Dnipro [2]. In this context, problem of rising and using "internal" ATE reserves, which basis is formed by the improvement of the technologies of passenger transportation process, is of special importance. Identification of those reserves along with their implementation is one of the main actions to improve economic and social parameters of the PMPT operation.

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Optimal vehicle fleet assignment to the routes is one of the possible technological measures aimed at improvement of ATE condition and quality of passenger transportation in terms of municipal bus routes. That assignment should include the following: possibility to obtain the required output information (results of passenger flow studies), stochastic nature of the transportation process; necessity to optimize two interrelated parameters – number and capacity of the route buses; and the available technological and social restrictions.

However, it should be noted that while solving the problem of optimal assignment, certain difficulties occur stipulated by the problem multivariance; that multivariance prevents form the problem solution by simple enumeration of possibilities. Moreover, majority of the available methodologies takes into account parameters of the passenger service quality but not the financial situation of ATE. Thus, in terms of modern conditions, a problem of vehicles assignment to the routes should be solved involving optimization methods, and target function (or its restriction) should consider needs and possibilities of all the participants of a transportation process.

2. Literature review

Solution of the problem of optimal vehicles assignment to the routes means the provision of equal satisfaction of the passengers' needs in term of their transportation on different routes taking into consideration a parameter of passenger service level, ATE costs, and technological restrictions (maximum traffic interval, bus stop capacity, number of buses etc.). In terms of its content, the problem belongs to the class of problems dealing with the production resources allocation aimed at reaching maximum efficient operation [3]. A method, in terms of which buses are assigned to the routes proportionally to the value of maximum passenger flows within the most loaded route section, is the most widely used one [4]. That method differs with its simplicity; however, it does not take into account quality of passenger service, effect of random factors, volumes and peculiarities of passenger flows within other (not so loaded) route sections, and structure of the fleet of vehicles being assigned.

Paper [5] represents different modifications of the assignment model [4] which propose to assign the routes proportionally to the volume of possible transport operation, proportionally to the transportation volumes, and proportionally to weighted average trip time. In term of the methods for bus assignment to the routes proposed in paper [6], bus traffic and passenger flow are analyzed with the consideration of random factors; probability of the fact that a passenger may not be allowed to board the bus on different routes is the criterion to assign buses. However, labour-consuming graphic constructions are required to obtain such solutions. That restricts the application of the methodology by the problems of research nature and complicates its use during short-time planning of transportation processes.

Thus, generalization of the analyzed assignment methodologies indicates that the models proposed in [4-6] are not optimization ones; correspondingly, the result, obtained with their help, is likely to be not optimal. However, main disadvantage of the majority of current assignment methodologies is in the fact that they were developed in 1970s-1990s before the changes in economic conditions on transport. Consequently, they do not take into consideration ATE interest in economic results of its activity.

3. Materials and methods

In recent years, numerous cities and towns in Ukraine have been demonstrating a tendency to the reduction in both volumes and quality of passenger transportation. That is the result of following factors: general economic crisis; reduced number of the vehicles due to their obsolete and technical depreciation; insufficient budgetary financing to cover losses due to the transportation of benefit-entitled passengers etc. All the mentioned factors result in unprofitability or low economic efficiency of the most Ukrainian ATEs.

While organizing ATE operation, one of the main tasks (having immediate effect upon the transportation efficiency) is the task to determine the route needs in the vehicle fleet [1,7,8]. That task consists of two sub-tasks: selection of bus capacity and number of buses as well as assignment of the buses to the routes. Both economic results of ATE operation and parameters of the passenger service (i.e. waiting interval, bus occupancy, possible denial for passengers to board the bus etc.) depends upon the qualitative and substantiated (involving current methods of system analysis) solution of those problems.

Unfortunately, insignificant attention is currently paid to the solution of problem concerning optimal assignment of vehicles to the routes. First of all, that fact is explained by insufficient professional qualification of ATE employees who tends to solve their economic problem at the expense of passengers; secondly, there are no unified criteria which would take into consideration the needs of both transporters and passengers. Thus, development of innovative models and methodologies (which will take into account current conditions of ATE operation) and obtaining optimal (rational) variants for bus assignment to the routes are rather burning issues.

DATP 11255 PJSC has been selected as the basic enterprise for the study. Currently, the enterprise services 6 municipal public routes. Passenger vehicle fleet includes 96 buses, 74% of which is accounted for Mercedes Sprinter and RUTA-22; the rest is accounted for BAZ A079, Bohdan A091, Bohdan A144, and Mercedes O345. Tables 1 and 2 represent assignment of buses to the routes and their basic characteristics respectively. Table 3 shows basic calculation categories for incomes and costs during the transportation process in 2018 (they were calculated on the basis of information represented in [9] as well as current route documents). Analysis of the data in Table 3 proves that nowadays *DATP 11255* PJSC is the unprofitable enterprise (at least, according to the released reports). Total amount of losses in 2018 was UAH 2 657 442. According to the employees of the AME operations department, problem of the bus assignment to the routes was of empiric nature without the use of optimization economic and mathematical methods and consideration of the majority of technical and operational parameters of the transportation process.

While organizing the operation of passenger transport, complexity of the approach while selecting optimal solutions is stipulated by internal contradictions of the parameters of ATE efficient operation and quality of passenger service. That is why, this problem is most often reduced to the problem with a single parameter, determining one (basic) criterion; other parameters are with the imposed restrictions.

Table 1. Current assignment of buses to *DATP 11255* PJSC routes.

Bus model	Passenger capacity	Route number						Total
		#33	#76	#76A	#79	#90	#156	
Mercedes Sprinter	18		16		11	8	18	53
Ruta-22	22	8		10				18
BAZ A079	40		10					10
Bohdan A091	50	4			5	2		11
Bohdan A144	80		2					2
Mercedes O345	92				2			2
Total		12	28	10	18	10	18	96

Table 2. Basic characteristics of the routes.

Parameter	Unit of measurement	Route number					
		#33	#76	#76A	#79	#90	#156
Tariff	UAH	7.0	7.0	7.0	7.0	10.0	7.0
Route length	km	17.4	19.6	18.7	16.1	26.4	20.7
Trip time	min	60	84	80	54	80	63
Operational speed	km/hour	17.4	14.0	14.0	17.9	19.8	19.7
Cruising speed	km/hour	24.4	19.6	19.6	25.0	27.7	26.8
Stops	unit	33	41	35	29	31	35

Table 3. Costs and incomes of *DATP 11255* PJSC in 2018.

Route number	#33	#76	#76A	#79	#90	#156	Total
Wages, UAH	2 289 925	4 298 158	1 930 958	2 148 883	1 736 134	2 017 257	14 421 318
Social deductions, UAH	915 970	1 228 045	508 147	920 950	631 322	1 100 322	5 304 757
Fuel and lubricants, UAH	6 106 467	10 745 394	3 760 286	5 986 173	5 208 403	7 702 256	39 508 988
Tyres, UAH	610 647	2 149 079	406 517	613 966	1 736 134	916 935	6 433 280
Amortization, UAH	1 221 293	1 842 068	813 035	1 074 441	1 420 474	1 467 096	7 838 409
Maintenance and repair, UAH	2 442 587	6 754 248	1 626 070	2 762 849	2 998 778	2 384 032	18 968 566
Other costs, UAH	1 679 279	3 684 135	1 117 923	1 841 899	2 051 795	2 750 806	13 125 840
Sum of costs , UAH	15 266 168	30 701 126	10 162 934	15 349 162	15 783 040	18 338 704	105 601 158
Total run, km	1 090 441	1 918 820	671 480	1 068 960	930 072	1 375 403	7 055 175
Trip time, hour	62 669	137 059	47 877	59 756	46 973	71 849	426 183
Number of trips	62 669	97 899	35 908	66 395	35 230	68 428	366 529
Anticipated income, UAH	16 875 323	31 953 326	12 756 845	16 566 482	16 693 314	25 027 515	119 872 806
Real income, UAH	14 681 531	30 355 659	9 950 339	14 578 504	15 357 849	18 019 811	102 943 694
Losses, UAH	584 637	345 467	212 595	770 658	425 191	318 893	2 657 441

Under conditions of complicated economic situation which is characteristic for the majority of ATEs (including the ones in Dnipro), optimality criterion should contain not only parameters of the service quality but also their economic efficiency. Taking into consideration all the aforementioned, the authors propose following structure for the model of optimal assignment of buses to the routes; in terms of the model, maximization of ATE income is the target function (depending upon the selected assignment variant), and restrictions are represented by non-exceedance of maximum admissible values of traffic interval and coefficients of bus capacity use:

$$\begin{cases} \sum_{i=1}^{m}\sum_{j=1}^{n} A_{ij}\cdot q_i \cdot D_{ij} \to \max & (1) \\ \gamma_j \le \gamma^{\max} = 1{,}2 & (2) \\ I_j \le I^{\max} = 15 \ \text{min}. & (3) \\ \sum_{j=1}^{n} A_{ij} = A_i & (4) \\ A_{ij} \ge 0 & (5) \end{cases}$$

where A_{ij} - is number of buses (taking into consideration specificity of obtaining input data at that stage, not the number of buses but number of departures) of ith model on jth route (assignment plan being developed); q_i - is capacity of ith bus model; D_{ij} - is income of ATE from the operation of a passenger unit of ith model on jth route; γ_j - is coefficient of bus capacity use in terms of the most loaded trip of jth route; $\gamma^{\max}$ - is maximum admissible coefficient of bus capacity use (taking into account control of transportation process quality, it is proposed to take $\gamma^{\max}$ =1.20 for all routes); I_j - is bus traffic interval on jth route; $I^{\max}$ - is maximum admissible bus traffic interval (taking into account control of transportation process quality, it is proposed to take $I^{\max}$ =15 min for all routes);

A_i - is available number of buses of i[th] model; m - is number of bus models being assigned; n - is number of routes being serviced.

Tables 1 and 2 represent basic parameters of the operation of DATP 11255 PJSC routes (operational velocity V_j, trip duration t_j, bus capacity q_i, fare T_j etc.) required to calculate constituents of the proposed models (1-5). Table 3 contains data on the constituents of prime cost of the transportation process required to calculate variable C_j^v and constant costs C_j^c for bus operation.

As for the data concerning values of the coefficient of passenger variation η_j, dynamic coefficients of bus capacity use γ_j^d, maximum values of passenger flows $H_j^{\max}$, and coefficients of capacity use in terms of the most loaded bus trip $\gamma_i^{\max}$, that information is possible to obtain only during the inspection of passenger flows.

Morning rush hour is the most important period for AME operation; thus, decision has been made to inspect passenger flows on all the routes of DATP 11255 PJSC from 8 a.m. to 9 a.m. (that is the period characterized by the greatest number of bus departures according to current bus schedules) only for direct route. To reduce labour consumption of the studies, recommendations from paper [10] were used as the substantiation of the sampling to guarantee sufficient accuracy of the obtained results. Basing upon recommendations [10] and current traffic interval, 21 bus trips are required to be studies in the context of the passenger flows inspection. Table 4 represents generalized information on the number of inspected trips, traffic intervals, and sampling percentage. Table 3 shows generalized results of the passenger flows inspection on DATP 11255 PJSC routes.

Basing upon the TEP data obtained during the inspection of passenger flows on DATP 11255 PJSC routes (Table 5), economic parameters of transportation process have been calculated which are required to obtain optimal bus assignment according to (1-5). Table 6 demonstrates the calculation results.

Problem of the vehicle fleet assignment to the municipal routes belongs to a special class of linear programming which are called transportation problems [1]. Special structure of a transportation problem helps apply following methods for its solution [11]: method of northwest angle, least-cost method, and Vogel's approximation method. According to the recommendations proposed in paper [7,10], it is appropriate to use Microsoft Excel SOLVER add-in while solving problems of mathematical programming with economic (technical) focus; that is a powerful auxiliary tool to perform complicated calculations including solution of the majority of mathematical programming problems.

Table 4. Substantiation of minimal number of trips for the inspection.

Route number		#33	#76	#76A	#79	#90	#156
Class I	Number of departures		1		1		
	Traffic interval, min		60		60		
	Selectivity, %		100%		100%		
	Number of inspections		1		1		
Class A	Number of departures	2	4		3	1	
	Traffic interval, min	30	15		20	60	
	Selectivity, %	50%	50%		67%	100%	
	Number of inspections	1	2		2	1	
Class B	Number of departures	4	5	4	6	3	9
	Traffic interval, min	15	12	15	10	20	7
	Selectivity, %	50%	40%	50%	33%	67%	33%
	Number of inspections	2	2	2	2	2	3
Departures, total		6	10	4	10	4	9
Inspections, total		3	5	2	5	3	3

Table 5. Basic technical and operational parameters of the routes serviced by *DATP 11255* PJSC during morning rush hour.

Parameter	Route number					
	#33	**#76**	**#76A**	**#79**	**#90**	**#156**
Number of the transported passengers	292	560	222	440	122	258
Proposed passenger capacity	188	330	88	350	104	162
Maximum passenger flow	182	428	158	328	93	216
Dynamic coefficient of the capacity use	0.63	0.88	1.21	0.63	0.72	0.86
Average duration of one passenger trip	7.0	10.2	8.9	8.0	16.2	11.2
Coefficient of variation	2.49	1.92	2.10	2.01	1.63	1.85

Table 6. Economic parameters of the operation of DATP 11255 PJSC routes.

Parameter	Bus model	Route number					
		#33	#76	#76A	#79	#90	#156
Tariff, UAH		7.00	7.00	7.00	7.00	10.00	7.00
Remuneration coefficient		0.91	0.93	0.91	0.92	0.90	0.89
Variablecosts, UAH/km		8.40	10.24	8.63	8.76	9.80	8.00
Constant costs, UAH/hour		97.44	80.64	91.28	100.18	83.16	105.14
Productivity, pas./seat		1.56	1.69	2.53	1.26	1.17	1.59
Income, UAH		9.92	11.03	16.14	8.12	10.53	9.91
Prime cost	Mercedes Sprinter	13.53	17.42	15.73	12.84	20.53	15.33
	Ruta-22	11.07	14.25	12.87	10.51	16.80	12.55
	BAZ A079	6.09	7.84	7.08	5.78	9.24	6.90
	Bohdan A091	4.87	6.27	5.66	4.62	7.39	5.52
	Bohdan A144	3.05	3.92	3.54	2.89	4.62	3.45
	Mercedes O345	2.65	3.41	3.08	2.51	4.02	3.00
Income	Mercedes Sprinter	-3.62	-6.39	0.42	-4.73	-10.00	-5.42
	Ruta-22	-1.16	-3.22	3.27	-2.39	-6.27	-2.64
	BAZ A079	3.83	3.19	9.07	2.34	1.29	3.01
	Bohdan A091	5.04	4.76	10.48	3.49	3.14	4.39
	Bohdan A144	6.87	7.11	12.60	5.23	5.91	6.46
	Mercedes O345	7.27	7.62	13.07	5.61	6.51	6.91

Output data for *SOLVER* add-in should be represented in the form of electronic table containing four range types:

- range of the problem variables;
- range of the specified problem parameters;
- range of the intermediate results;
- range of the target functions.

Range of the problem variables is the obligatory one; its configuration reminds a form of ATE fleet matrix *A* being assigned. Each box of the range corresponds to one element A_{ij} of matrix A which corresponds to the number of bus departures of *i*th model operating on *j*th route. Variable box should not contain any formulas.

Range of the specified problem parameters is the obligatory one containing constants preset by the problem condition. In terms of the problem of bus assignment to the routes, that range has four constituent parts:

- sub-range for income matrix $D = [D_{ij}]$;

- sub-range for the vector assigning number of buses of i^{th} model $K = [A_i]$ (at this stage, A_i means number of departures of i^{th} bus model within the time period being considered);

- sub-range for the vector of maximum admissible value of the coefficient of bus capacity use on j^{th} route $\gamma^{\max}$ = [$\gamma_j^{\max}$]=1.2;

- sub-range for the vector of maximum admissible bus traffic interval on j^{th} route $I^{\max}$ = [$I_j^{\max}$]=15 min.

Boxes of all the sub-ranges should not contain any formulas. All the output data should be entered into those sub-ranges before the beginning of the problem solving.

Range of the intermediate results contains formulas representing dependences between the table data being distributed within the three sub-ranges:

- sub-range of passenger-unit assignment to the routes Q =[Q_{ij}] for the products of matrix *A* elements by corresponding elements of matrix *q*. Each box should contain a formula determining product $A_{ij} \cdot q_i$.

- sub-range of restriction functions of type (2) determining values of the coefficient of the vehicle fleet capacity use within the most loaded trip γ_j on j^{th} route. That is a mandatory range; each of its boxes contains following formula: $\gamma_j^{\max} = \dfrac{H_j^{max}}{\sum_{i=1}^{m} Q_{ij}}$.

- sub-range of the restricted-type functions (3) determining interval of bus trip I_j on j^{th} route. That is mandatory range; each of its boxes contains following formula: $I_j = \dfrac{60}{\sum_{i=1}^{m} A_{ij}}$.

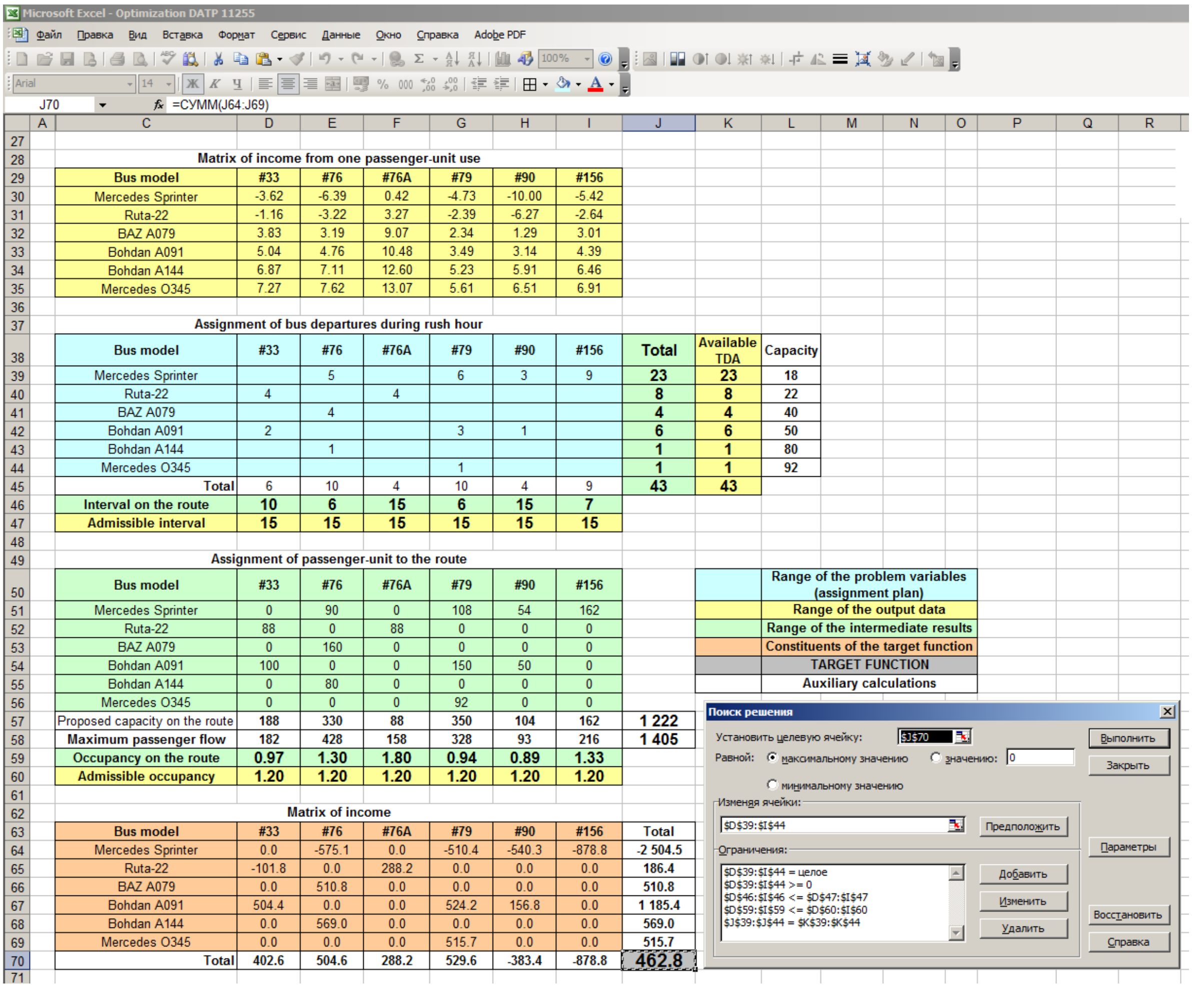
- sub-range of the restriction function of type (4) determining number of buses of i^{th} model being assigned on j^{th} route. That is a mandatory range; each of its boxes contains formula $\sum_{j=1}^{n} A_{ij}$.

Range of the target function F should consist one (and only one) box with the formula to determine criterion (1), i.e. formula of double sum $\sum_{i=1}^{m}\sum_{j=1}^{n} F_{ij}$.

To evaluate the efficiency of optimal vehicle fleet assignment to the routes, first of all, value of target function (1) in terms of the available organization of transportation process at *DATP 11255* PJSC should be determined.

Owing to the fact that technical and operational parameters of the routes operation (Table 5) were obtained during the passenger flow inspection during morning rush hour (8 a.m. – 9 a.m.), current bus assignment to the routes should be understood *not as the number of buses reserved for the routes* (Table 1), *but the number of their departures within the period being analyzed*. Figure 1 shows data concerning the number of departures of i^{th} bus model on j^{th} route. Those data are the range of problem variables. Each box of the range corresponds to one element A_{ij} of matrix A.

To determine value of target function (1), it is required to calculate matrix of the proposed passenger-units $Q_{ij} = A_{ij} \cdot q_i$ and matrix of the target function constituents $F_{ij} = D_{ij} \cdot Q_{ij}$. Results of calculated Q_{ij} and F_{ij} for current assignment are also represented in Fig.1. The obtained results prove that the proposed capacity of buses on the routes are less that its demand (1 222<1 405), i.e. transportation process is performed in terms of deficit being 183 passenger-units. Income of *DATP 11255* PJSC from 8 a.m. to 9 a.m. is UAH 462.8. Moreover, it should be noted that in terms of routes #76, #76A, and #156, maximum values of the coefficients of bus capacity is much higher than the admissible ones having negative effect upon the quality of passenger service.



Matrix of income from one passenger-unit use

Bus model	#33	#76	#76A	#79	#90	#156
Mercedes Sprinter	-3.62	-6.39	0.42	-4.73	-10.00	-5.42
Ruta-22	-1.16	-3.22	3.27	-2.39	-6.27	-2.64
BAZ A079	3.83	3.19	9.07	2.34	1.29	3.01
Bohdan A091	5.04	4.76	10.48	3.49	3.14	4.39
Bohdan A144	6.87	7.11	12.60	5.23	5.91	6.46
Mercedes O345	7.27	7.62	13.07	5.61	6.51	6.91

Assignment of bus departures during rush hour

Bus model	#33	#76	#76A	#79	#90	#156	Total	Available TDA	Capacity
Mercedes Sprinter		5		6	3	9	23	23	18
Ruta-22	4		4				8	8	22
BAZ A079		4					4	4	40
Bohdan A091	2			3	1		6	6	50
Bohdan A144		1					1	1	80
Mercedes O345				1			1	1	92
Total	6	10	4	10	4	9	43	43	
Interval on the route	10	6	15	6	15	7			
Admissible interval	15	15	15	15	15	15			

Assignment of passenger-unit to the route

Bus model	#33	#76	#76A	#79	#90	#156	
Mercedes Sprinter	0	90	0	108	54	162	
Ruta-22	88	0	88	0	0	0	
BAZ A079	0	160	0	0	0	0	
Bohdan A091	100	0	0	150	50	0	
Bohdan A144	0	80	0	0	0	0	
Mercedes O345	0	0	0	92	0	0	
Proposed capacity on the route	188	330	88	350	104	162	1 222
Maximum passenger flow	182	428	158	328	93	216	1 405
Occupancy on the route	0.97	1.30	1.80	0.94	0.89	1.33	
Admissible occupancy	1.20	1.20	1.20	1.20	1.20	1.20	

Matrix of income

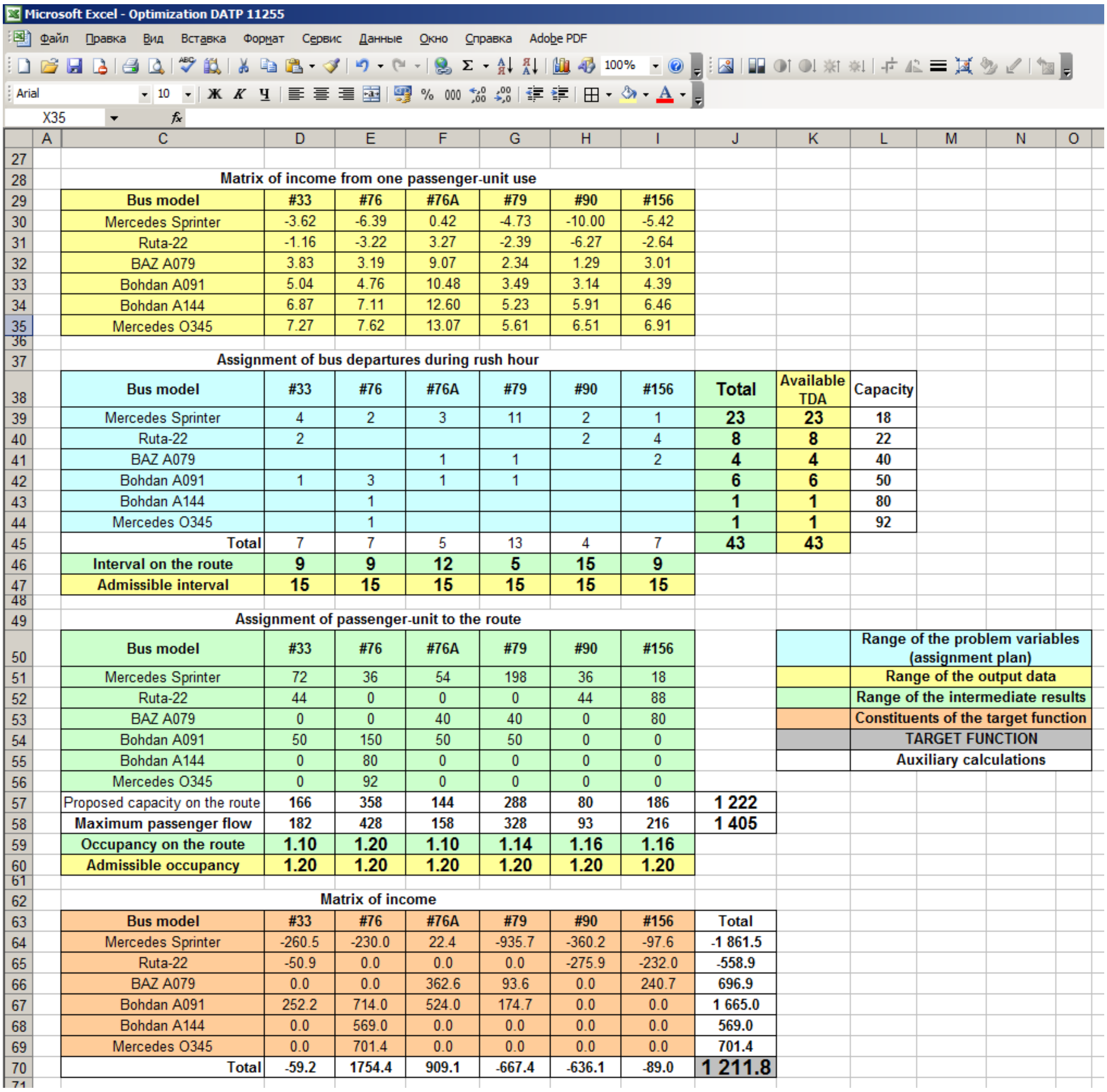
Bus model	#33	#76	#76A	#79	#90	#156	Total
Mercedes Sprinter	0.0	-575.1	0.0	-510.4	-540.3	-878.8	-2 504.5
Ruta-22	-101.8	0.0	288.2	0.0	0.0	0.0	186.4
BAZ A079	0.0	510.8	0.0	0.0	0.0	0.0	510.8
Bohdan A091	504.4	0.0	0.0	524.2	156.8	0.0	1 185.4
Bohdan A144	0.0	569.0	0.0	0.0	0.0	0.0	569.0
Mercedes O345	0.0	0.0	0.0	515.7	0.0	0.0	515.7
Total	402.6	504.6	288.2	529.6	-383.4	-878.8	462.8

Figure 1. Work sheet of the prepared data for *SOLVER* add-in operation.

Optimal assignment of *DATP 11255* PJSC buses was performed with the help of *Microsoft Excel SOLVER* add-in. To perform the calculation, it is required:

- to call up *SOLVER* add-in: *Service →Solver*;
- to indicate target box (*J70*) – functional (1);
- to indicate optimization direction – maximum value;
- to indicate variable boxes (*$D$39:$I$44*) – assignment plan A_{ij} ;
- to enter restrictions: (*$D$59:$I$59<=$D$60:$I$60*) – restriction (2); (*$D$46:$I$46<=$D$47:$I$47*) – (3); (*$J$39:$J$44=$K$39:$K$44*) – (4) and (*$D$39:$I$44>=0*) – restriction (5);

Figure 2 represents the results of *Microsoft Excel* SOLVER add-in. Thus, optimal assignment of *DATP 11255* PJSC vehicles for morning rush hour has been obtained. Analysis of the information given in Figure 2 confirms that *DATP 11255* PJSC income may be increased by 2.62 times (from UAH 462.8 up to UAH 1211.8). In addition, improvement of the transportation process quality should be emphasized as all the mentioned values of maximum coefficient of the buses capacity use are not more than admissible value $\gamma_j < \gamma^{max}$ =1.20.



Matrix of income from one passenger-unit use

Bus model	#33	#76	#76A	#79	#90	#156
Mercedes Sprinter	-3.62	-6.39	0.42	-4.73	-10.00	-5.42
Ruta-22	-1.16	-3.22	3.27	-2.39	-6.27	-2.64
BAZ A079	3.83	3.19	9.07	2.34	1.29	3.01
Bohdan A091	5.04	4.76	10.48	3.49	3.14	4.39
Bohdan A144	6.87	7.11	12.60	5.23	5.91	6.46
Mercedes O345	7.27	7.62	13.07	5.61	6.51	6.91

Assignment of bus departures during rush hour

Bus model	#33	#76	#76A	#79	#90	#156	Total	Available TDA	Capacity
Mercedes Sprinter	4	2	3	11	2	1	23	23	18
Ruta-22	2				2	4	8	8	22
BAZ A079			1	1		2	4	4	40
Bohdan A091	1	3	1	1			6	6	50
Bohdan A144		1					1	1	80
Mercedes O345		1					1	1	92
Total	7	7	5	13	4	7	43	43	
Interval on the route	9	9	12	5	15	9			
Admissible interval	15	15	15	15	15	15			

Assignment of passenger-unit to the route

Bus model	#33	#76	#76A	#79	#90	#156	
Mercedes Sprinter	72	36	54	198	36	18	
Ruta-22	44	0	0	0	44	88	
BAZ A079	0	0	40	40	0	80	
Bohdan A091	50	150	50	50	0	0	
Bohdan A144	0	80	0	0	0	0	
Mercedes O345	0	92	0	0	0	0	
Proposed capacity on the route	166	358	144	288	80	186	1 222
Maximum passenger flow	182	428	158	328	93	216	1 405
Occupancy on the route	1.10	1.20	1.10	1.14	1.16	1.16	
Admissible occupancy	1.20	1.20	1.20	1.20	1.20	1.20	

	Range of the problem variables (assignment plan)
	Range of the output data
	Range of the intermediate results
	Constituents of the target function
	TARGET FUNCTION
	Auxiliary calculations

Matrix of income

Bus model	#33	#76	#76A	#79	#90	#156	Total
Mercedes Sprinter	-260.5	-230.0	22.4	-935.7	-360.2	-97.6	-1 861.5
Ruta-22	-50.9	0.0	0.0	0.0	-275.9	-232.0	-558.9
BAZ A079	0.0	0.0	362.6	93.6	0.0	240.7	696.9
Bohdan A091	252.2	714.0	524.0	174.7	0.0	0.0	1 665.0
Bohdan A144	0.0	569.0	0.0	0.0	0.0	0.0	569.0
Mercedes O345	0.0	701.4	0.0	0.0	0.0	0.0	701.4
Total	-59.2	1754.4	909.1	-667.4	-636.1	-89.0	1 211.8

Figure 2. Results of *Microsoft Excel SOLVER* add-in operation.

As previously stated, the obtained optimal distribution of buses to the routes (Figure 2) should be understood not as the number of buses reserved for the routes but as the number of their departures per period being analyzed. Thus, the obtained optimal plans of the departure assignments do not allow yet reserving all the vehicles of *DATP 11255* PJSC for municipal routes being serviced.

At the moment, 96 buses (Table 1) are operated on the routes of *DATP 11255* PJSC; assignment was performed for 43 vehicles (Table 1) as that is the amount of buses which is involved in transportation process for which TEP (Table 5) have been determined on the basis of passenger flows inspection.

Final reserving of *DATP 11255* PJSC vehicle fleet for the municipal routes being serviced require additional assignment of 53 buses more (96–43=53) so that following condition will be met:

$$\sum_{j=1}^{n} A_{ij}^{final} = A_i \,. \tag{6}$$

Final number of buses of i^{th} model which should operate on j^{th} route may be determined according to following dependence:

$$A_{ij}^{final} = A_{ij} + A_{ij} \cdot k_i \,, \tag{7}$$

where k_i is coefficient taking into account a degree of unassigned buses of i^{th} model:

$$k_i = \frac{A_i - \sum_{j=1}^{n} A_{ij}}{\sum_{j=1}^{n} A_{ij}}. \quad (8)$$

Table 7 represents the results of calculation of the unassigned buses of i^{th} model according to (8). Table 6 shows the results of calculations of final reserving of *DATP 11255* PJSC vehicle fleet for the routes (7).

Table 7. Calculation of the non-assignment degree k_i of i^{th} model buses.

Bus model	$\sum_{j=1}^{n} A_{ij}$	A_i	$A_i - \sum_{j=1}^{n} A_{ij}$	k_i
Mercedes Sprinter	23	53	30	1.30
Ruta-22	8	18	10	1.26
BAZ A079	4	10	6	1.50
Bohdan A091	6	11	5	0.83
Bohdan A144	1	2	1	1.00
Mercedes O345	1	2	1	1.00
Total	43	96	53	

Table 8. Final optimal assignment of buses to *DATP 11255* PJSC routes

Bus model	**Passenger capacity**	**Route number**						**Total**
		#33	**#76**	**#76A**	**#79**	**#90**	**#156**	
Mercedes Sprinter	18	9	5	7	25	5	2	53
Ruta-22	22	5				5	8	18
BAZ A079	40			3	3		4	10
Bohdan A091	50	2	5	2	2			11
Bohdan A144	80		2					2
Mercedes O345	92		2					2
Total		16	14	12	30	10	14	96

4. Conclusions

Topicality of the solution of the problem concerning optimal vehicles assignment to the municipal routes in terms of ATEs of the city of Dnipro has been substantiated. The available models to assign buses to the routes has been analyzed with the specification of their area of application, basic advantages and disadvantages.

Structure of the model for optimal assignment of buses to the routes has been proposed; in terms of that structure, maximization of ATE income is a target function while restriction is represented by non-exceedance of maximum admissible values of traffic interval and coefficients of bus capacity use.

Microsoft Excel SOLVER add-in has been applied to obtain optimal assignment of buses departure making it possible the following: to increase *DATP 11255* PJSC income by 2.62 times (from UAH 462.8 up to UAH 1211.8); to improve quality of transportation process at the expense of decrease in maximum coefficient of bus capacity use to the limits of permissible value $\gamma^{\max}$ =1.20; to provide non-exceedance of maximum admissible traffic interval of buses $I^{\max}$ =15 min. Final reserving of *DATP 11255* PJSC vehicle fleet for the routes has been performed on the basis of the calculated coefficient k_i which takes into consideration a degree of unassigned buses of i^{th} model.

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