The Determination of the Optimal Variant of Public Bus Line Transport Vehicles in the Daily Circulation

Određivanje optimalne varijante transportnih vozila javne autobusne linije u dnevnom protoku

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Summary

This paper presents the possible solutions of daily circulations in terms of the transport ensuring the daily performance of vehicles and staffing. It is focused on the determination of these vehicles as the daily circulation optimal variant as well. It appears that the analysis of the transport solution is the first step to determine the successful optimal solution of the transport performance volume. Subsequently, the transport solution must be tested from an economic point of view.

KEY WORDS
optimal variant
public line bus transport
vehicles
daily circulation
models

Sažetak

U radu su izložena moguća rješenja za dnevni protok u smislu prijevoza kojim se može osigurati dnevna izvedba vozila i osoblja. Cilj je također odrediti vozila koja bi predstavljala optimalnu dnevnu varijantu. Moglo bi se zaključiti da je analiza prijevoznog rješenja prvi korak ka određivanju uspješnog optimalnog rješenja za količinu prijevozna. Stoga se prijevozno rješenje mora testirati s ekonomskog gledišta.

KLJUČNE RIJEČI
optimalna varijanta
javna autobusna linija
vozila
dnevni protok
modeli

INTRODUCTION

The implementation and operation of public line bus transport is the daily task of the selected transportation company. It is a process, which is implemented by the time conditioned deployment of the necessary transport technology (transport capacity) and space arrangement of the individual source and destination stops. Both the conditions are defined by a timetable, which is elaborated as the requirement reflecting the transport needs of the inhabitants.

The beginnings of transfer relations are called the sources and the ends and they are also called destinations. Then transport relations are the result of the difference between the transfer relations in total and the walks. Transport relations are established by the conversion of transfer relations to the necessary number of vehicles in a process called the distribution of transport performance. Transport relations quantify the basic indicators both in the preparation itself and in the environment where the transport is implemented.

THE IMPORTANT REGULATORY FUNCTIONS, ORGANIZATION AND MANAGEMENT OF THE TRANSPORT PROCESS

The process of the provision of the daily transport task can be described and quantified. It is based on its feasibility. Each process is loaded by regular quantifiers which may be determined and the coincidental quantifiers that enter randomly into the process.

The following may be included among the basic regulatory functions [1]:

a) the regularity of the transport task: both time and spatial,
b) the feasibility of a transport task with the optimum number of vehicles and drivers,
c) the cost that is necessary for the provision of the required transport system function.

This article does not deal with the complete solution of the transport performance distribution. It assesses transport relations within a selected transport company at the level of the division of transport systems and the existing structure of the centres from which the transport task is solved [1], [2].

DAILY CIRCULATION AS AN IMPORTANT OPERATIONAL PARAMETER OF THE PROCESS

Daily vehicle circulation (the turn, the introductory order etc.) is the basic output from the daily dispatcher activity. The daily circulation represents the basic sum of the necessary economically substantiated costs to be spent on fulfillment of the transport task.

The base for its evaluation is [3], [4]:

a) a feasibility assessment,

- organizational,
- in terms of safety at work,

b) an assessment of the total necessary cost.

The company then evaluates all of the daily circulations and the solution quality is usually expressed by the [3]:

a) total quantity of necessary transport technology,
b) total number of necessary drivers,
c) number of kilometres done in one turn (one vehicle),
d) total number of necessary unproductive kilometres,
e) total waiting hours of the transport technology,
f) complexity of the weekly and fortnightly circulations, their differences and repeatability possibilities.

THE BASIC EVALUATION METHODS

The implementation process of the daily circulations is a quantifiable one. The basic quantifiers are also the descriptive characteristics that may be compared and evaluated. We usually talk about direct quantities, which are expressed by the basic descriptive values of distance, time, number etc. and on the derived quantities, which are related to a performance element, activity or the performance itself [3] - [5].

The quantitative indicators serve as the expression and description of the qualitative process indicators. The non-measurable quantities need to be expressed through the measurable ones for the whole process evaluation [5].

THE QUANTITATIVE INDICATORS

The whole transport activity can be described as the performed transport performance in the transport task implementation. The following quantitative indicators are used to describe and evaluate the performed transport performance [2], [5]:

a) descriptive, which characterize the transport task size and the size of vehicles solving the task
b) performance, describing necessary time deployment and use of vehicles for the daily transport task
c) derived, formed by the combination of the descriptive and performance indicators

For the needs of the study the structure of indicators is as follows (*Table 1*):

Table 1 The summary of the input and output indicators

Input indicators	Output indicators
Costs per km [CZK]	Number of links inselected region
Costs of waiting [CZK/min]	Number of links
Daily costs [CZK/bus]	Number of links turns
Timetable - link time reduction	Number of drives
Obligatory handling BEFORE	Number of kilometres according to timetable
Obligatory handling AFTER	Number of pass kilometres
Maximum price of a passage	Number of overhead km
Passage up to 5 km	Operation time – Start
Passage 5 – 10 km	Operation time – End
Passage 10 – 20 km	Total operation time
Passage over 20 km	Total time of drive
Travel to the source place	Other times
Adherence to H&S	Operation time in timetable
Method	Total driving time in timetable
Critical cut	Average operation time
Minimum receipt	Average drive time
Not to include without receipt	Number of turns to modification
	Number of shifted links
Optimizationaccording to price	Number of shortened links
Price of a bus	Number of passages
Minute of waiting	Laying on times
Costs per km	Number of laying on drives
Extra driver	Number of laying km
	Links not included - number
	Links not included - km
	Transport price [CZK]

Source: authors

THE QUALITATIVE INDICATORS

The qualitative indicators usually evaluate a set of several quantifiable indicators that improve quality and effectiveness of the incurred costs, time etc. [2], [4].

More quantifiers (the total operation time, the total drive time, the number of daily circulations, and the number of drivers) can be used for the evaluation of daily circulations.

THE OPERATIONAL ANALYSIS AND THE OPERATIONAL RESEARCH METHODS

Numerous methods are used in solving the optimized number of daily circulations. However, these methods are based on thelong-term experience of experts. Empiric methods are also applied in some situations. However, it is quite complicated to find a real criterion for the evaluation of the optimum number of daily circulations [6] - [8].

The application of graph theory methods is the base of the solution of the daily circulations in our approach. A large number of applicable operation research methods exist, such as the solution of the graph algorithm problems [7], [9].

The maximum number of realized links at a time point (the so called "Critical Cut") is the basic criterion for the comparison of the effectiveness of the achieved result of the number of necessary daily circulations [6], [7].

The applied method evaluates not only the current links, but in the case of the composition of the circulations (the so called "Raw circulations") also shows how many the means of transport are at the maximum cut passing between the previous destination stop and the next source stop [7], [9].

The "Shortest Path Method" calculated from the existing routes of the valid timetables is applied to the passages because of the ensuring the passing ability of the transport technology. The speed of the passages is defined by the distance where determination of passage speed is based on the consideration that the shortest passages are in the city districts and the longest distances are in passing the long lines at the highest speed (see *figure 1*). The value of the passage speed setting is assigned in the calculation solution [9], [10].

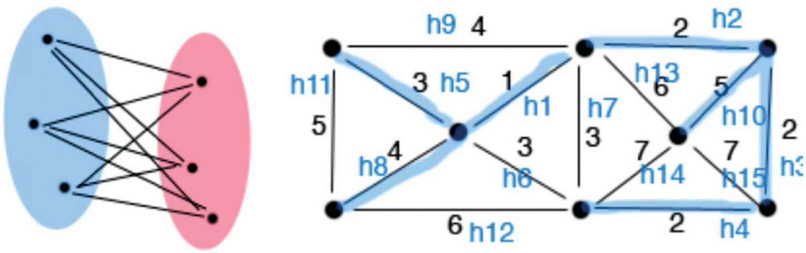

Figure 1 Examples of the Shortest Path Method

Source: authors

THE PREPARATION OF A MODEL OF ORGANIZATION AND MANAGEMENT OF PUBLIC BUS TRANSPORT

A MODEL OF THE DAILY CIRCULATIONS OF THE COMPANY AS A WHOLE WITHOUT THE DIVISION OF OPERATIONS AND TRANSPORT TECHNOLOGY TYPES

This model is the basic one in preparation of transport task solution models [9]. Its importance is in initial quantification of the individual transport and operation indicators. The proportional indicators showing the basic parameters of the expected solution have to be expressed in the assignment (*table 2*).

The presented values are as follows as the:

a) average speed of a link is constant unless timetables are generally modified
b) average drive time of a link also represents a constant value
c) average waiting time is a value that can be influenced within the performed model
d) average link length is also constant; a change would involve a change of timetables.

The Model Variant Evaluation (*table 3):*

The model reflects the lowest value of the daily circulations; the time values are higher than in timetables. This is caused by the higher number of kilometres that arise from the drives between the destination stop of the previous link and the source stop of the next link [5], [9].

Table 2 Basic parameters of the expected model solution

	Parameter	Values	Average and link
Variant total	Number of links	1547	
	Operation time in timetable	1416:22:00	0:54:56
	Number of km acc. to timetable	29,098	18,809
	Number of links in time table	96	
	Number of t determined links	398	
	Number of operations	2	
	Driving time according to TT	830:57:00	0:32:14
	Waiting time according to TT	585:25:00	0:22:42
	Average speed	35.02	

Source: authors

The variant may also be generally expressed by means of the value of the funds, if we introduce the values for vehicle use, the cost of waiting, the cost of km of passage and the cost of the second shift of drivers.

Table 3 The evaluation of the model variants

Parameter	Value	Result	Value
Costs per km [CZK]	25	Number of links in selected region	96.007
Costs of waiting [CZK/min]	0.005	Number of links	1547
Daily costs [CZK/bus]	5000	Number of links turns	100
Timetable - link time reduction	0	Number of drives	1720
Obligatory handling BEFORE	0	Number of kilometres acc. to TT	29098
Obligatory handling AFTER	0	Number of pass kilometres	961
Maximum price of a passage	5000	Number of overhead km	1255
Passage up to 5 km	35	Operation time – Start	03:28
Passage 5 – 10 km	45	Operation time – End	00:32
Passage 10 – 20 km	55	Total operation time	1469:10
Passage over 20 km	65	Total time of drive	852:30
Travel to the source place	yes	Other times	616:40
Adherence to H&S	NO	Operation time in timetable	1464:08
Method	2	Total driving time in timetable	830:57
Critical cut	440	Average operation time	14:41
Minimum receipts		Average drive time	08:31
Not to include without receipts	0	Number of turns to modification	24
		Number of shifted links	0
Optimization according to price	NO	Number of shortened links	0
Price of a bus	1500	Number of passages	148
Minute of waiting	1	Laying on times	05:02
Costs per km	20	Number of laying on drives	25
Extra driver	100	Number of laying km	294
		Links not included - number	0
		Links not included - km	0
		Transport price [CZK]	796460

Source: authors

Input values:

Cost of vehicle use (without operational costs)	CZK 1,500 per day
Price of one minute of waiting	CZK 1 per minute
Operation costs	CZK 20 per km
Extra cost of extra driver	CZK 100 per circulation

The costs of the presented optimized model are CZK 796,460 per day.

A MODEL OF THE DAILY CIRCULATIONS OF THE COMPANY AS A WHOLE WITH THE DIVISIONACCORDING TO THE TRANSPORT SYSTEMS (HIGH CAPACITY TRANSPORT, MPT, OTHER TRANSPORT)

The model enables the separation of the defined links according to the required vehicle type. It is based on a file of input data, which determine the final solution (*table 4*).

It is obvious from the above table of individual model parts:

The variant of separation of the set of high capacity links increases the number of daily circulations to 104,

The variant of separation of the set of the municipality transport links and the integration of the set of high capacity links to the other links particularly increases the number of daily circulations in the others group, namely from 88 circulations to 95 circulations, This is caused by low number of high capacity vehicles and time incompatibility of long distance and suburban transport

The variant with separated set of high capacity links and other links without separation to others and municipal as one operation is interesting in terms of economy as it represents 104 daily circulations (vehicles). Total price is CZK 795,033 per day.

The variant of separation of the set of municipal links and leaving the set of high capacity links in the set of others represents CZK 813,043 per day.

THE MODEL OF THE DAILY CIRCULATIONS ACCORDING TO THE OPERATIONS

This article now focuses on the evaluation of the possibility to retain the existing organizational structure for the transport task fulfilment. The company is now divided into two operations and the transport task is fulfilled by the mutual coexistence of the links according to the operations.

Table 4 The values of the individual parts of the model

Monday 2.11.2009 51.0001 61.0001			High capacity convoy (HC)	All without HC	All without MPT	MPT
			131.0003	31.0001 + 41.0001		
Parameter	Value	Result	Value	Value	Value	Value
Costs per km [CZK]	25	Number of links in region	11.002	88:007	85:006	12
Costs of waiting [CZK/min]	0.005	Number of links	100	1447	1249	298
Daily costs [CZK/bus]	5000	Number of links turns	12	92	95	12
Timetable - link time reduction	0	Number of drives	101	1594	1367	311
Obligatory handling BEFORE	0	Number of kilometres acc. to TT	3 614	25484	26608	2490
Obligatory handling AFTER	0	Number of pass kilometres	0	476	926	16
Maximum price of a passage	5000	Number of overhead km	0	709	1258	20
Passage up to 5 km	35	Operation time – Start	03:35	03:28	03:28	4:05:00
Passage 5 – 10 km	45	Operation time – End	22:44	00:17	00:14	23:30:00
Passage 10 – 20 km	55	Total operation time	173:48	1351:05	1401:07	166:55:00
Passage over 20 km	65	Total time of drive	95:27	747:53	747:12	105:27:00
Travel to the source place	YES	Other times	78:21	603:12	653:55	61:28:00
Adherence to H&S	YES	Operation time in timetable	173:48	1346:59	1395:38	166:49:00
Method	2	Total driving time in TT	95:27	735:30	725:58	104:59:00
Critical cut	339	Average operation time	14:29	14:41	14:44	15:28:00
Minimum receipts		Average drive time	07:57	08:07	07:51	10:00:00
Not to include without receipts	0	Number of turns to modification	2	18	18	3
		Number of shifted links	0	0	0	0
Optimization according to price	YES	Number of shortened links	0	0	0	0
Price of a bus	1500	Number of passages	1	124	96	11
Minute of waiting	1	Laying on times	00:00	04:06	05:29	0:06
Costs per km	20	Number of laying on drives	0	23	22	2
Extra driver	100	Number of laying km	0	233	332	4
		Links not included - number	0	0	0	0
		Links not included - km	0	0	0	0
		Transport price [CZK]	95181	699852	740855	72188

Source: authors

The basic classification for the evaluation is as follows:

a) each operation operates all transport systems (suburban, long-distance, municipal transport),
b) the removal of the set of long distance links with necessity of a high capacity means of transport,
c) the removal of the set of municipal links and the set of links with a high capacity means of transport.

The values of the individual parts of the models can be seen in *table 5*.

Table 5 The values of the individual parts of the model

Monday 2.11.2009			HC is not separated				
			A - withoutMPT	B - without MPT	MPT - A	MPT - C	Total 101.0001 + 21.0002 + 31.0001 + 41.0001
			101.0001	21.0002	31.0001	41.0001	
Parameter	Value	Result	Value	Value	Value	Value	Value
Costs per km [CZK]	25	Number of links in region	32.008	52.007	10	2	96.007
Costs of waiting [CZK/min]	0.005	Number of links	428	821	283	15	1547
Daily costs [CZK/bus]	5000	Number of links turns	33	56	10	2	101
Timetable - link time reduction	0	Number of drives	463	887	296	15	1661
Obligatory handling BEFORE	0	Number of kilometres acc. to TT	9634	16974	2333	157	290098
Obligatory handling AFTER	0	Number of pass kilometres	276	466	16	0	758
Maximum price of a passage	5000	Number of overhead km	304	551	20	0	875
Passage up to 5 km	35	Operation time – Start	3:35	3:28	4:05	5:25	3:28:00
Passage 5 – 10 km	45	Operation time – End	23:44	0:15	23:30	17:30	23:44:00
Passage 10 – 20 km	55	Total operation time	483:06:00	816:39:00	154:48:00	12:07	1466:40:00
Passage over 20 km	65	Total time of drive	266:40:00	474:33:00	100:06:00	5:21	846:40:00
Travel to the source place	YES	Other times	216:26:00	342:06:00	54:42:00	6:46	620:00:00
Adherence to H&S	YES	Operation time in timetable	482:34:00	815:04:00	154:42:00	12:07	1464:27:00
Method	2	Total driving time in timetable	261:35:00	464:23:00	99:38:00	5:21	830:57:00
Critical cut	339	Average operation time	14:38	14:34	15:28	6:03	14:29:58
Minimum receipts		Average drive time	8:04	8:28	10:00	2:40	8:22:58
Not to include receipts	0	Number of turns to modification	13	22	3	0	38
		Number of shifted links	0	0	0	0	0
		Number of shortened links	0	0	0	0	0
		Number of passages	31	56	11	0	98
		Laying on times	00:32	01:35	00:06	00:00	2:13:00
		Number of laying on drives	4	10	2	0	16
		Number of laying km	28	85	4	0	117
		Links not included - number	0	0	0	0	0
		Links not included - km	0	0	0	0	0
		Transport price [CZK]	262546	457226	65646	6546	791960
Variant D		101.0001+21.0001+31.0001+41.0001	101				
Variant E		172.0001+151.0001+51.0001 +31.0001+41.0001					

Source: authors

The above variants show that the variants of the separate operations and the separation of the MPT representthecost value of CZK 791,960 per day. This variant requires more overhead kilometres and less transport technology. The number of drivers can be derived from the number of daily circulations and the number of turns to be modified, i.e. 139 drivers per day.

The variants of separation of the set of high capacity vehicles, the MPT and other suburban transport links represent the cost value of CZK 814,551 per day.

DRAWING UP THE OPTIMUM VARIANT OF DAILY CIRCULATIONS

After calculation of the model variants we are now able to modify the individual daily circulations from the point of view of the applicable regulations for the work of MPT drivers and bus crews for the selected variant.

The model is performed and it turns out feasible after the modification conversions to the daily circulation.

THE DEFINITIONS OF THE QUANTIFIERS DESCRIBING THE EVALUATION OF THE DAILY CIRCULATION MODELS

The following indicators and their achieved values are important for the variant evaluation [10], [11]: a) the number of daily circulations, b) the number of overhead km, c) the total operation time, d) the total drive time, e) other times (waiting), f) the operation time in the timetables, g) the driving time in the timetables, h) the number of drivers (the number of daily circulations + the number of turns to be modified), i) the average operation time, j) the average driving time, k) the total cost of the above variant implementation, l) the number of high capacity and other means of transport.

The indicators sufficiently describe the overall possibilities of the evaluation of the individual models. However, the decision of the selected variant also depends on the indicators representing the specifics of the individual operations and the company as a whole (the parking spaces, the activities in idle times etc.).

However, this article solves the variant that best reflects the above defined indicators in general.

THE DETERMINATION OF THE OPTIMUM VARIANT OF DAILY CIRCULATIONS AND THE STATISTIC INDICATORS OF THE OPTIMUM MODEL

After the evaluation of the individual variants (the quantification of their transport and economic indicators), we can choose the optimum variant for the further processing of the daily circulations to the form of the feasible transport performance (*table 5*).

Variants A, B, C given below describe the possible solutions of the separation of the links according to the requirements for the transport system (vehicle).

Variant A is a variant obtained by the separation of a set of links for high capacity vehicles (12) and the rest with the acceptation and modifications in the system of the set of links left of the MPT. The variant involves partial use of suburban transport vehicles for the MPT in the times of no peaks in the MPT. The daily need of drivers is 130.

Variant B is a variant obtained by the separation of the set of links for the MPT and a set that also includes high capacity vehicles. The analyses shown above reveals that the increase of the number of vehicles is caused by the strict requirement for the set of high capacity links, which are operated by the fixed number of high capacity vehicles (12). The daily need of drivers is 128.

Variant C is a variant obtained as a whole set of all of the links without the division to the sets of specific links. This variant is only feasible with higher than the existing number of high capacity vehicles (35). The daily need of drivers is 124.

We used a basic method for the evaluation of the most favourable variant for processing the daily circulations: the method of assessed order of important operational indicators. It is based on the quantification of the individual operational indicators and their comparison with the financial appraisal of the model.

Table 6 contains the evaluation of the most favourable variant for processing the daily circulations.

Table 6 The evaluation of the most favourable variant for processing the daily circulations

The company as a whole			Variant A	Variant B	Variant C
			51.004 + 61.0001	131.0001 + 31.0001 + 41.0001	1.0001
Position according to costs			1	5	3
Position according to number of circulations			3	5	1
Position according to overhead km			1	5	4
Position according to Other times (waiting)			4	5	1
Total			9	20	9
Average			2.25	5	2.25

Source: authors

Variants A and C prove to be suitable for the solution. Variant C is infeasible if the requirement for the limited number of vehicles for the set of high capacity links is to be adhered to.

Thus *Variant A* is a variant requiring 104 vehicles and the lowest number of overhead kilometres and the slightly increased indicator of the other times (waiting). The total value of the variant implementation as the solution of the transport task is CZK 795,835 per day.

CONCLUSION

This article has shown the possible solutions of the daily circulations in terms of ensuring the daily performance of vehicles and staffing. An analysis of the transport solution has shown to be the first step in the determination of a successful and optimum solution of the transport performance volume. However, the transport solution should also be subject to the economic solution.

The requirement for the type structure of the service on the defined links and the real number of vehicles of the required type and their transport capacity is another important indicator for the determination of optimum solution. Diversification of a unified type increase costs both in the process of ensuring the transport performance and in the company investments [1], [10]-[13].

The organization and management process is permanently conditioned by the changes of the economic and legislative conditions for the transport task implementation. It is always necessary to set the basic priorities of the solution and the subsequent interpretation which substantially influences the whole solution of given optimizing task.

The whole process of planning, management and control is then conditioned by the duration of processing the task into a feasible form. Introduction and permanent monitoring of the important indicators then brings final effect: cost saving both in the form of the solution found and in the form of investments into renewal of transport technology.

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