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# THE POSIBILITIES OF BUS SETS USING

*In transport, as well as in other areas of our life, there are still used knowledge or experience proved in the past. Of course, these are modernized with progressing development as it is in the field of mass passenger transport and related bus trailers. At present, when the economic situation in mass passenger transport puts pressure on us to minimize the costs as much as possible, especially operation costs. This article present the operation evaluation of the transport system. with using the trailer vehicles.*

***Keywords**: bus, transport system, operational evaluation*

## 1. Introduction

In transport, as well as in other areas of our life, there are still used knowledge or experience proved in the past. Of course, these are modernized with progressing development as it is in the field of mass passenger transport and related bus trailers. These trailers were used, in the past, in forming the bus sets. Even though their use was gradually quitted in our country, they successfully operate in some cities abroad up to now [1].

At present, when the economic situation in mass passenger transport puts pressure on us to minimize the costs as much as possible, especially operation costs, it is suitable to think on reinstalling passenger transport system with using the trailer vehicles. In Slovakia, there are used, nowadays, single vehicles (buses, trolley-buses, trams) or articulated vehicles. Articulated vehicles are suitable for coverage of higher traffic requirement in traffic peak or single vehicles circulated in shorter line intervals ensure this increase requirement [2, 3].

Vehicle connection and set operation are permissible if instantaneous weight of a trailer is at most 1,5 multiple of instantaneous weight of towing vehicle (Fig.1 and fig 2) in a set with the highest design speed exceeding 30 km/h. The distance between the last axle of motor vehicle, which total weight exceeds 3.5 t, and the first axle of trailer, which total weight exceeds 3.5 t, must be at least 3.0 m.

*Fig. 1 The buses with trailer*

Non-motor vehicle of *O* category, with exception of non-motor vehicle of *O* category which must not be connected in back of motor vehicle with design speed exceeding 25 km/h, has to be equipped by brake equipment system which must fulfil the conditions set up by special regulation (Communication of the Ministry of Foreign Affairs No. 245/1996 Code - EEC Regulation No. 13, 78 and 90).

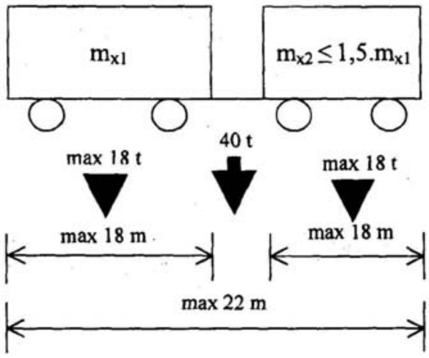


*Fig. 2 The view of the maximum dimensions and weights*

## 2. Operation evaluation

For simplification of this evaluation we will install a model line of mass urban transportation which route runs from point A to point B. The service length of this line is $l_z$ = 10 km and number of intermediate stops between terminal stations A and B is $n_z$ = 10. Total number of passengers carried on the line per day is *O* = 10 000 passengers. Of this, *O1* = 60000 passengers will carry in peak hours (from 5:00 a.m. to 8:30 a.m. and from 13:00 p.m. to 16:30 p.m.) and *O2* = 4000 passengers in off-peak hours (from 8:30 a.m. to 13:30 p.m. and from 16:30 p.m. to 22:00p.m.). Vehicle (set) capacity utilization coefficient in peak hours is $\gamma_1$ = 1.0 and in off-peak hours $\gamma_2$ = 0.8. Vehicle (set) time spent at the terminal station is $t_k$ = 5 min.

The aim is to compare transport output *L* [km] under the specified conditions at these two eventualities:

*1st eventuality*

The bus of Karosa B 931 type with occupancy *K* = 94 passengers runs on the line (as, in fact, mostly). Time which bus will stay at the stop is on average $t_z$ = 30 s. Technical speed of the bus is $v_t$ = 25 km/ h.

2nd *eventuality*

The bus set, recommended in Chapter 4.4.7, consisting of bus SOR 9.5 (for mass urban transportation needs adapted for city bus) and two-axle passenger trailer, runs on the line during peak hours. Occupancy of the whole set is *K* = 164 passengers. Average value $t_z$ = 24 s is less than at 1st eventuality. During off-peak hours the single bus is running on the line after dismounting the trailer at the terminal station. Its occupancy is $K = 80$ passengers. Average value of delay at the stop is 24 s as well, because saddle traffic is concerned and also due to timetable uniformity during the day. Average technical speed of the set in peak hours and the bus in off-peak hours is less than at 1st eventuality $v_t = 23$ km/ h.

### A. Calculation of transport capacity $O_p$

$$O_{pi} = \frac{O_i}{t_{pi}} \; [seats/h] \tag{1}$$

where $O_i$ is number of passengers carried during service time $t_{pi}$.

a) traffic peak: $O_{p1} = \dfrac{6000}{6,5} = 924 \;\; seats/h$

b) saddle traffic: $O_{p2} = \dfrac{4000}{10,5} = 381 \;\; seats/h$

### B. Calculation of line interval i

$$i_i = \frac{K_i \cdot 60 \cdot \gamma_i}{O_{pi}} \; [min] \tag{2}$$

where $K_i$ is occupancy of vehicle (set) $\gamma_i$ is coefficient of its utilization.

*1st eventuality:*

a) traffic peak: $i_1 = \dfrac{94 \cdot 60 \cdot 1,0}{924} \approx 6 \;\; min$

b) saddle traffic: $i_2 = \dfrac{94 \cdot 60 \cdot 0,8}{381} \approx 11 \;\; min$

*2nd eventuality:*

a) traffic peak: $i_1 = \dfrac{164 \cdot 60 \cdot 1,0}{924} \approx 10 \;\; min$

b) saddle traffic: $i_2 = \dfrac{80 \cdot 60 \cdot 0,8}{381} \approx 10 \;\; min$

### C. Calculation of required number of vehicles (sets) in circulation on the line $N_i$

$$N_i = \frac{t_o}{i_i} = \frac{2t_l}{i_i} = \frac{2(t_i + n_z t_z + t_k)}{i_i} \; [vehicles \; (sets)] \;\; t_j = \frac{l_z}{60 v_t} \; \Big| \tag{3}$$

where $t_o$ is turning time [min], $t_l$ is line time [min] a $t_j$ is running time [min].

*1st eventuality:*

a) traffic peak:

$$N_1 = \frac{2(24 + 10 \cdot 0,5 + 5)}{6} = \frac{2 \cdot 34}{6} \approx 11 \;\; vehicles$$

b) saddle traffic:

$$N_2 = \frac{2(24 + 10 \cdot 0,5 + 5)}{11} = \frac{2 \cdot 34}{11} \approx 7 \;\; vehicles$$

*2nd eventuality:*

a) traffic peak:

$$N_1 = \frac{2(26 + 10 \cdot 0,4 + 5)}{10} = \frac{2 \cdot 35}{10} \approx 7 \;\; sets$$

b) saddle traffic:

$$N_2 = \frac{2(26 + 10 \cdot 0,4 + 5)}{10} = \frac{2 \cdot 35}{10} \approx 7 \;\; vehicles$$

### D. Calculation of vehicle (set) transport output $L_i$

$$L_i = n_{si} l_z N_i \; [km] \;\; n_{si} = \frac{t_{pi}}{t_l} \; [links] \tag{4}$$

where $n_{si}$ is number of links of one vehicle (set).

*1st eventuality:*

a) traffic peak: $L_1 = 12 \cdot 10 \cdot 11 = 1320 \;\; km$

b) saddle traffic: $L_2 = 19 \cdot 10 \cdot 7 = 1330 \;\; km$

*2nd eventuality:*

a) traffic peak: $L_1 = 11 \cdot 10 \cdot 7 = 770 \;\; km$

b) saddle traffic: $L_2 = 18 \cdot 10 \cdot 7 = 1260 \;\; km$

At 1st eventuality, when single bus Karosa B 931 is set on the line, drive output is

$L = 1320 + 1330 = 2650$ km. At 2nd eventuality, when bus set SOR 9,5 + two-axle trailer are set on the line, the drive output is $L = 770 + 1260 = 2030$ km. Drive output will decrease approximately by a quarter at the 2nd eventuality.

If we want to use bus set on the line, we have to solve a problem of connecting the trailer in back of the bus. That means to equip SOR 9,5 bus by towing equipment. This would be possible to solve by double redrilling the rear bumper, bracing the rear part of bus steel grid (due to stress by tensile resistance) and by welding up another traverse for rear bumper. To this traverse it would be possible to tighten towing equipment with cylindrical pin through one opening in bumper. The other opening would serve for compressed air inlet to trailer brakes, etc. Towing equipment would be automatic in order to connect the trailer by driver without assistance of other person. Moreover, it would be necessary to enlarge double-flow braking set of the bus by the other circle for the trailer and to adapt its parameters.

But in terms of legislation (§ 104 of NR SR Act No. 725/2005 Code, on road traffic), modification of supporting frame regards as vehicle transformation. The transformation must not realize without authorization of the National Transport Authority. The vehicle transformation is followed by reauthorisation of its technical qualification, i.e. conformity certification (homologation) of vehicle, its components and equipment. The investment in such transformation would amount about 125 000 SKK including an approval procedure.

## 3. Economic gain

So we can evaluate installing the bus sets in the Slovak Republic in terms of economic aspect. One of the main aspects is an acquisition price of the currently produced trailer (about 8.5 mill. SKK) which exceeds, more than doubly, the price of a single bus SOR 9.5 (3.7 mill. SKK) whereas the price of articulated bus, e.g. Karosa B 941, is only about 4.5 mill. SKK. However, it is necessary to take into account its life time – 20 years. The other possibility is production of the trailer with similar design by a company based in Slovakia with lower production costs, with that would relate also lower investment costs of transport companies at purchase of trailer.

In decision making on bus trailer purchase the carriers have to take into account also the costs associated with bus set operation. The most important amount of these costs is fuel costs.

We consider standard line of mass urban transportation on which the bus Karosa B 931, with average consumption of 32 litres of fuel oil for 100 km, runs. Theoretical value of consumption under certain operation conditions we can find with using resistances as follows:

$$M = \frac{\sum O}{\eta_m \eta_c H_u} \; [kg/m] \tag{5}$$

where ∑O is total of running resistances, $\eta_m$ is total engine efficiency, which varies with operation conditions (we consider value 0.7), $\eta_c$ is total gearbox efficiency (0.9) and $H_u$ is fuel oil efficiency (41 848 kJ/ kg).

Following substitution and modification it applies:

$$M = \frac{mg\left(f + \frac{a}{g}\delta\right) + 0.05 c_x S V^2}{\eta_m \eta_c H_u} \; [kg/m] \tag{6}$$

Following substitution of known values

$$M = \frac{17000 \cdot 9.81 \cdot \left(0.01 + \frac{0,4}{9.81} \cdot 1.07\right) + 0.05 \cdot 0.7 \cdot 6.65 \cdot 60^2}{0.7 \cdot 0.9 \cdot 41840000} = 0.00037 \;\; kg/m$$

It is possible to calculate this value using fuel oil density 0.85 kg/ dm$^3$ per consumption in litres for 100 km. Then it is $M$ = 43.7 l/ 100 km.

It is possible to use this relationship also for calculation of theoretic consumption of bus set. For simplification we will consider with connecting the trailer in back of bus Karosa B 931.

$$M_s = \frac{29000 \cdot 9.81 \cdot \left(0.01 + \frac{0.4}{9.81} \cdot 1.07\right) + 0.05 \cdot 0.9 \cdot 6.65 \cdot 60^2}{0.7 \cdot 0.9 \cdot 41840000} = 0.00062 \;\; kg/m$$

$$M_s = 72.9 \;\; l/100km$$

The difference between values $M_s$ and $M$ represents value 29.2 l/ 100km by which bus consumption will increase when we connect the trailer behind it. After adding this value to real consumption of a single bus Karosa B 931 we will obtain consumption value after trailer connection: 32 + 29.2 = 61.2 l/ 100 km. If we added difference between $M_s$ and $M$ to consumption of bus SOR 9,5 from recommended bus set, we will obtain the value 26 + 29.5 = 55.5 l/ 100 km, which is comparable to consumption of articulated bus Karosa B 941 (52 l/ 100 km).

Under 1st eventuality in Chapter 5.1 the consumption per daily output will be 2650 ·32/ 100 = 848 litres of fuel oil and under 2nd eventuality it will be 770 ·55.5/ 100 + 1260 ·26/ 100 = 755 litres of fuel oil. The second eventuality is therefore economically more profitable in terms of consumption.

## 4. Conclusion

The bus sets ran in urban and suburban traffic in the past but their service was gradually given up for safety reasons and they were be replaced by articulated buses.

At present, however, high-quality and safe bus trailers are produced, which abroad, especially in the Switzerland, normally run and are successfully mainly due to silent running, good steerability and minimal maintenance.

In Slovakia, it would be also desirable to install this mode of passenger transport, mainly, by reason of increasing transport capacity. Great advantage of this is possibility to modify operatively the capacity of traffic unit by simple connecting or disconnecting the trailer, which is not possible at articulated bus. Trailers, disconnected at the terminal stations, could be used on various lines what could improve their utilization and reduce down times.

In the Slovak transport companies, mostly each driver has an assigned bus so if articulated bus instead of single one is set on the line in peak hours, one more driver, minimally, runs on the line. When using the trailers it might not happen.

The problem of bus trailers is regulated by legislation. Passenger trailer should have to fulfil the conditions given by laws in force nowadays. These conditions are mostly applicable also in other European countries therefore the imported trailer would be appropriate for operation in our country.

With respect to operation and economic evaluation this system would be more appropriate with trailer of lower acquisition price made in Slovakia. It wouldn't be necessary to purchase new buses but only properly modify those that run nowadays.

Therefore prospective producers of passenger trailers and their potential operators should consider this possibility.

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