SCHEMATIC SCHEDULE OF SUBURBAN TRAINS ON WEEKENDS

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ABSTRACT

A special feature of suburban transportation is uneven distribution of passenger traffic over the seasons of the year, the days of the week and the hours of the day. In view of such differentiation by the hour of the day, the schedule of suburban trains on pre-weekend and weekend days differs significantly from the schedule on working days. The article proposes a technique for maximizing the number of suburban trains in the traffic schedule for the weekend with a fixed number of trains, which allows for a smooth transition from the basic traffic schedule to the schedule during the peak period without increasing the number of trains in circulation.

Keywords: *railway transport, suburban trains, transportation process, organization of passenger transportation.*

Background. *Suburban passenger transportation differs from long distance transportation and local traffic by a number of significant features. These include mass, uneven distribution by zones, seasons, days and hours of the day [1].*

An important feature is uneven distribution of suburban passenger traffic over the seasons of the year, the days of the week and the hours of the day. As many authors [2–4] note, because of the similar nature of the hourly distribution, the schedule of suburban trains on pre-weekend and weekend days differs significantly from the schedule on working days. The analysis of real traffic patterns and distribution of suburban passenger traffic over the time of day and the length of the suburban sector on working days and weekends shows [5] that it is necessary to increase the size of train traffic during non-intensive periods during the weekend. In addition, it is required to extend the routes of a part of the trains that follow to the near technical zones. Therefore, when constructing a schedule for the weekend, the problem arises of increasing the number of suburban trains in the total turnover, which leads to significant economic losses. To solve the problem in these circumstances, the increase in the size of traffic should be achieved only through intensification of the use of suburban trains, without increasing their fleet.

Objective. *The objective of the authors is to consider schematic schedule of suburban trains on weekends.*

Methods. *The authors use general scientific methods, comparative analysis, evaluation approach, and mathematical apparatus.*

Results. *The basis for development of a schematic schedule on weekends is the schedule of suburban trains and the schedule of commuter traffic on working days. Previously [6, pp. 212–219] the issue of scheduling trains for suburban trains on pre-weekend and weekend days was already considered, but in the proposed methodology, linkages are made separately for each suburban station, which leads to an increase in the dimension of the task.*

The method of constructing a schematic schedule of train traffic on weekends is explained in the calculation example. A similar technique was used [7] to intensify the movement of long-distance passenger trains during peak periods, but significant differences in organization of suburban and long-distance passenger transportation make it necessary to make certain adjustments to the former versions.

Arrange in ascending order all the moments of arrival and departure of trains at the commuter traffic station in a schematic schedule on weekdays of the week. Let's designate t_i^k – train arrival schedules at the commuter traffic train station k, and T_j^q – departure schedules from station q.

The mathematical model of the task of constructing a schematic schedule on weekends is an integral linear model with Boolean variables

$$x_{ij}^{kq} = \begin{cases} 1, if\ t_i^k \text{ is linked with } T_j^q \\ 0, otherwise. \end{cases} \quad (1)$$

Since each arrival schedule can be linked with only one departure schedule and, conversely, each departure schedule – with only one arrival schedule, the variables x_{ij}^{kq} satisfy the following system of equations:

$$\begin{cases} \sum_{i=1}^{n} x_{ij}^{kq} = 1,\ \forall j = \overline{1,n} \\ \sum_{j=1}^{n} x_{ij}^{kq} = 1,\ \forall i = \overline{1,n} \end{cases} \quad (2)$$

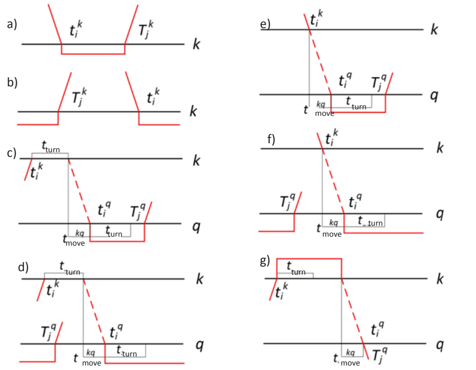
Let's introduce the matrix of estimates of linkage of the arrival schedules t_i^k with the departure schedules T_j^q with the elements:

$$\begin{cases} C_{ij}^{kk} = \begin{cases} 0, if\ t_i^k + t_{turn} \le T_j^k \\ 1, if\ t_i^k + t_{turn} > T_j^k,\ \forall i, j; \end{cases} \\ C_{ij}^{kq} = \begin{cases} 0, if\ t_i^k + t_{turn} + t_{move}^{kq} \le T_j^q; q \ne k \text{ if train movement direction remains}, \\ 0,\ if\ t_i^k + 2t_{turn} + t_{move}^{kq} \le T_j^q;\ q \ne k \text{ when train movement direction changes}, \\ 1,\ otherwise. \end{cases} \end{cases} \quad (3)$$

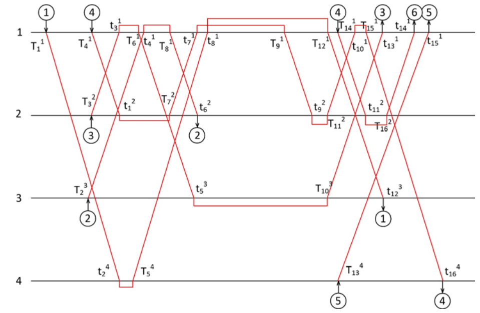
Here t_{turn} – turnover rate of commuter trains at the station.

The options for linking the schedules t_i^k with T_j^q and T_j^k are shown in Pic. 1.

The number of trains moving in a suburban area with a fixed variant of linking the schedules of arrival and departure of trains is determined from the condition for minimizing the value:



Pic. 1. Options for linking the schedules of arrivals and departures of commuter trains, where a) and b) – linking schedules to one station; c) and d) – linking schedules to different stations with a change in the direction of trains; e), f), g) – linking schedules to different stations without changing the direction of the trains.



Pic. 2. Schematic schedule of suburban trains at the calculated training site on weekdays of the week.

the column corresponding to the mark, remove the single linkage from the cell of the line corresponding to the marking of this line, and so on, until we mark the line originally selected by the line. In our example, we removed the linkage from the cells (1, 13) and (7, 16), and introduced linkages in the cells

Table 1

Matrix of estimation of linkages of schedules $\{C_{ij}^{kq}\}$ with initial linkage

	T_1^1	T_2^3	T_3^2	T_4^1	T_5^4	T_6^1	T_7^2	T_8^1	T_9^1	T_{10}^3	T_{11}^2	T_{12}^1	T_{13}^4	T_{14}^1	T_{15}^1	T_{16}^2	
t_1^2	1	1	1	1	1	1	0	0	0	0	0	0	0 [1]	0	0	0	13
t_2^4	1	1	1	1	0	1	0	1	0 [1]	0	0	0	0	0	0	0	9
t_3^1	1	1	1	1	1	0	0	0	0	0 [1]	0	0	0	0	0	0	10
t_4^1	1	1	1	1	1	1	0 [1]	0	0	0	0	0	0	0	0	0	
t_5^3	1	1	1	1	1	1	1	1	0	0	0	0 [1]	0	0	0	0	12
t_6^2	1	1	1	1	1	1	1	1	0	0	0	0	0	0 [1]	0	0	14
t_7^1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0 [1]	16
t_8^1	1	1	1	1	1	1	1	1	0	0	0 [1]	0	0	0	0	0	11
t_9^2	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0 [1]	0	15
t_{10}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	–
t_{11}^2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	–
t_{12}^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–
t_{13}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–
t_{14}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–
t_{15}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–
t_{16}^4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–
							1	1	7	7	7	7	7	7	10	10	

$$M = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}^{kq} x_{ij}^{kq}. \quad (4)$$

The task of minimizing the total number of trains (4) under constraints (1)–(3) is equivalent to the task of placing the largest number of units in the zero cells of the value matrix, provided that no more than one unit can be placed in each matrix row.

As an example, consider a schematic schedule on weekdays for a suburban area with four stations of commuter traffic (Pic. 2).

For an example of a schematic schedule of suburban trains on the working days of the week, shown in Pic. 2, six trains will be needed. The linking of the trains will be done according to the procedure given in [8].

To develop a schedule for commuter trains on weekends, we will compile a matrix of linkage of schedules $\{C_{ij}^{kq}\}$ (Table 1), assuming $t_{turn} = 0$.

The process of solving the task begins with an arbitrary permissible allocation of units to the zero matrix cells $\{C_{ij}^{kq}\}$. Let's put the unit in the thirteenth cell of the first line (with the largest run of the train).

Then we delete the first row and the thirteenth column and continue this procedure until we get a matrix consisting of only units.

Let's mark the line that does not contain single linkages ($x_{ij}^{kq} = 1$).

We look through the marked rows, find the zero cell and mark the corresponding column with the number of this line, go to the next marked, not yet viewed line, and so on, until all the marked lines are passed.

We look through the marked column, find in it a single linkage ($x_{ij}^{kq} = 1$) and mark the corresponding row with the number of this column and so on, until we have passed all the marked columns.

Then we move on to viewing the rows and marking the columns.

There are two possible cases: either the process of placing markers will be interrupted, or we will mark a column that does not contain single linkages.

In the first case, we get the optimal linkage of the arrival schedules to the departure schedules. In the second, it is possible to increase the number of linkages per unit. To do this, following the notations, we enter the single linkage to the cell of

Table 2

Matrix of estimation of linkages of schedules $\{C_{ij}^{kq}\}$ after recalculation of linkages

	T_1^1	T_2^3	T_3^2	T_4^1	T_5^4	T_6^1	T_7^2	T_8^1	T_9^1	T_{10}^3	T_{11}^2	T_{12}^1	T_{13}^4	T_{14}^1	T_{15}^1	T_{16}^2
t_1^2	1	1	1	1	1	1	0	0 1	0	0	0	0	0	0	0	0
t_2^4	1	1	1	1	0	1	0	1	0 1	0	0	0	0	0	0	0
t_3^1	1	1	1	1	1	0	0	0	0	0 1	0	0	0	0	0	0
t_4^1	1	1	1	1	1	1	0 1	0	0	0	0	0	0	0	0	0
t_5^3	1	1	1	1	1	1	1	1	0	0	0	0 1	0	0	0	0
t_6^2	1	1	1	1	1	1	1	1	0	0	0	0	0	0 1	0	0
t_7^1	1	1	1	1	1	1	1	1	0	0	0	0	0 1	0	0	0
t_8^1	1	1	1	1	1	1	1	1	0	0	0 1	0	0	0	0	0
t_9^2	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0 1	0
t_{10}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0 1
t_{11}^2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
t_{12}^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
t_{13}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
t_{14}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
t_{15}^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
t_{16}^4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

(1, 8), (7, 13) and (10, 16). The resulting matrix is shown in Table 2.

Conclusion. *Further recalculation is not possible, because the process of marking is interrupted. We have obtained the optimal linkage of the schedules shown in Pic. 3, which provides an increase in the size of the movement of electric trains to five pairs with the same number of trains in circulation.*

REFERENCES

1. Dranchenko, Yu. N. Features of organization of suburban passenger transportation in various countries of the world [*Osobennosti organizacii prigorodnyh passazhirskih perevozok v razlichnyh stranah mira*]. *Vestnik transporta*, 2015, Iss. 10, pp. 28–33.

2. Vakulenko, S. P., Kolin, A. V. On the criteria of determination of the categories of commuter trains. *World of Transport and Transportation*, Vol. 10, Iss. 6, pp. 16–21.

3. Verkhovykh, G. V., Zaitsev, A. A., Kotenko, A. G. [*et al*]. Rail passenger transportation: Monograph [*Zheleznodorozhnye passazhirskie perevozki: Monografija*]. Ed. by G. V. Verkhovykh. St. Petersburg, Center «Rusich», «Pallada-Media», 2012, 520 p.

4. Kurenkov, P. V., Dranchenko, Yu. N., Volkova, S. A. Scientific and methodological recommendations for solving priority tasks for passenger transportation in the city-suburb system [*Nauchno-metodicheskie rekomendacii po resheniju pervoocherednyh zadach dlja passazhirskih perevozok v sisteme «gorod-prigorod»*]. *Transport: nauka, tehnika, upravlenie*, 2016, Iss. 1, pp. 4–13.

5. Pazoysky, Yu. O., Vakulenko, S. P., Kolin, A. V. [*et al*]. Organization of suburban railway transportations: Study guide [*Organizacija prigorodnyh zheleznodorozhnyh perevozok: Ucheb. posobie*]. Ed. by Yu. O. Pazoysky. Moscow, TMC for education in railway transport, 2015, 270 p.

6. Pazoysky, Yu. O., Shubko, V. G., Vakulenko, S. P. Passenger transportations by rail (examples, tasks, models, methods and solutions) [*Passazhirskie perevozki na zheleznodorozhnom transporte (primery, zadachi, modeli, metody i reshenija)*]. Moscow, TMC for education in railway transport, 2015, 342 p.

7. Pazoysky, Yu. O., Saveliev, M. Yu., Baturin, A. P. Maximization of the number of passenger long-distance trains during the growth of passenger traffic due to intensification of the use of trains. [*Maksimizacija chisla passazhirskih poezdov dal'nego sledovanija v period rosta passazhiropotokov za schjot intensifikacii ispol'zovanija sostava poezdov*]. *Konkurentosposobnost' v global'nom mire: ekonomika, nauka, tehnologii*, 2016, Iss. 9, pp. 166–172.

8. Pazoysky, Yu. O., Saveliev, M. Yu., Milkov, A. Yu. Linking trains of passenger trains of different purposes to the general turnover [*Uvjazka sostavov passazhirskih poezdov raznyh naznachenij v obshhij oborot*]. *Transport: nauka, tehnika, upravlenie*, 2015, Iss. 9, pp. 7–14.

9. Vakulenko, S. P., Kurenkov, P. V., Dranchenko, Yu. N. Review and analysis of scientific research of passenger transportation in the metropolitan city-suburb system [*Obzor i analiz nauchnyh issledovanij passazhirskih perevozok v megapolisnoj sisteme «gorod-prigorod»*]. *Vestnik transporta*, 2016, Iss. 9, pp. 37–42.

10. Vakulenko, S. P., Kopylova, E. V., Belyankin, A. Yu. Feasibility assessment of development of passenger service system. *World of Transport and Transportation*, Vol. 13, 2015, Iss. 2, pp. 122–128.

11. Gudkova, V. P. State regulation in the sphere of passenger transportation [*Gosudarstvennoe regulirovanie v sfere passazhirskih perevozok*]. *Ekonomika zheleznyh dorog*, 2013, Iss. 4, pp. 76–84.

12. Dranchenko, Yu. N. Railway in the city [*Zheleznaja doroga v gorode*]. *Zheleznodorozhnyj transport*, 2013, Iss. 12, pp. 81–84.

13. Kurenkov, P. V., Andreev, A. V. Scientific and methodological proposals for increasing the efficiency of the suburban railway transport complex [*Nauchno-metodicheskie predlozhenija po povysheniju effektivnosti raboty prigorodnogo kompleksa zheleznodorozhnogo transporta*]. *Vestnik transporta*, 2008, Iss. 12, pp. 31–34.

14.Rezer, S. M. Logistics of passenger transportation by rail: Monograph [*Logistika passazhirskih perevozok na zheleznodorozhnom transporte: Monografija*]. Moscow, VINITI RAN publ., 2007, 515 p. ●

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