Supplementary Materials

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Expanding routing procedure and functional layers of public passenger transport lines

The basic input in the process of planning regional lines of public passenger transport is the knowledge of mutual transport dependencies between individual sources and destinations on the network within a pre-defined region - the region Prešov. These dependencies are displayed using the source-target matrix, or graphically through a network graph, where individual vertices (nodes) represent resources and goals in the territory, while rated and directional edges show the direction and intensity of passenger transport flows.

The ideal input is a complex transport model of the region being addressed with the characteristics of transport flows of all types of transport in different parts of the day, with a forecast of future development, as well as a description of important dependencies - especially of a socioeconomic nature (purposes of roads, slope, imbalance of work and housing, demography, territorial development). The output can be several variants of line management within certain parts (segments) of the transport network, if it is possible to ensure the connection of two centres on the network either by railway or bus line, the routes of which, however, are different due to the transport infrastructure, which consequently affects the line service of intermediate settlements.

The process of creating the design of routing and functional layers of regional lines of public passenger transport in terms of the hierarchy of nodes on the network is shown in the manuscript in the form of a flow diagram in Figure 4. It is described in more detail in the following paragraphs.

1. Routing of regional public passenger transport lines

Nodes on the network need to be divided based on the hierarchy, ideally into 3 to 4 categories. The node of the 1st category is the natural centre of gravity of the solved functional region. Nodes of the 2nd and 3rd categories are local catchment centres (district towns, resort villages, etc.), while nodes of the last (3rd or 4th) category are all other settlements, usually of a small rural character. The number of categories depends on the size, as well as the traffic and settlement structure of the region. Such a structure is shown in figure S1 in this appendix.

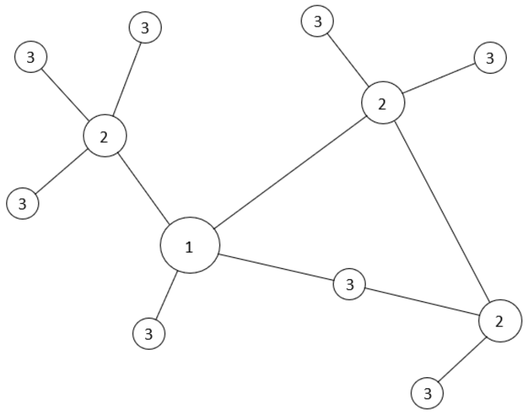

Figure S1: Example of hierarchical connection of settlements by public passenger transport lines. Source: authors

Routing of lines in the ideal (or theoretical) case, it is necessary to lead them from a node of a higher category in a "radial" manner to settlements of a lower category level, from these in a similar way to settlements of a lower category level and proceed similarly to the settlements of the lowest category. This means that each node should be directly connected to the corresponding drop centre of the next higher level. Logically, the nearest catchment centre for a node of the 4th category can also be a node of the 1st category (a typical example is satellite rural settlements in the vicinity of large regional centres).

A theoretical example of the hierarchical connection of settlements by public passenger transport lines is shown in Figure S1 (the numbers define the category of the settlement). In addition to the hierarchical supply of lower-category nodes to higher-category nodes, it is also necessary to consider the potential of direct interconnection of settlements of the same category (in express or stop mode), especially if they are connected by a suitable transport infrastructure and there are significant transport dependencies between them.

2. Functional layers of regional public passenger transport

From the point of view of the functional layers, the lines defined in this way need to be further divided into express (expedited) lines, able even on longer routes to compete with individual automobile transport at speed, and stop lines, serving all the municipalities on the route with the most suitable availability of stops from the point of view of residents - ideal up to 500 m (approx. 5 to 7 minutes' walk), maximum up to 1,500 m (approx. 15 to 20 minutes' walk).

Even in the case of the functional definition of lines, it is necessary to start from the hierarchical distribution of nodes on the network. In the case of the above-mentioned division into 4 categories, it is generally desirable to run lines between 1st and 2nd category residences in express mode (because of the attractive connection of the main points of settlement concentration - compared to individual car transport), lines between 3rd and 4th categories due to area service in stop mode (in the case of extremely low intensity of transport flows in the form of demand-responsive service) and lines between 2nd and 3rd category residences either in express or stop mode based on parameters such as the distance between nodes, the routing of the transport route from the point of view of service roadside settlements, transport speed, or the intensity and direction of passenger flows, so that their operation is attractive to customers, but at the same time economically sustainable.

3. Potential transport flows

Band or express service should be properly implemented where, thanks to it, it is possible to achieve an extension of the radius of daily commuting in the vicinity of an economic centre capable of absorbing an additional influx of labour (usually a seat of the 1st category, or 2nd category). An effective way of finding the potential of transport flows (or limits of daily commuting) in public passenger transport is to observe daily commuting flows in individual automobile transport (applies in cases where individual car transport is the fastest way of commuting to the relevant economic centre). Based on this, it is possible to determine from what distance (from which towns and villages) residents are still willing to commute daily to the centre of the region, or another seat within the region, which has a relatively attractive offer of job opportunities.

From the point of view of the theory, the radius of the daily commute is limited by time - in our conditions, 1 hour is considered the limit time of an attractive commute. However, this refers to the total travel time (from point A to point B), including walking and waiting. The principle here is that a regular passenger should not spend more than 2 hours commuting daily (the journey "to" + the journey "from" work or school). In this sense, the attractive time limit from boarding the first means of transport in the source location to exiting the last means of transport in the destination location is around 45 to 50 minutes (under normal conditions). Expanding the territory from which most of the able-bodied population is willing to commute daily to the economic centre of this territory (using public passenger transport) is an effective tool for transforming potential transport flows of public passenger transport into real transport flows.

4. Intermodality within regional public passenger transport

According to our proposal, the maximum acceptable number of transfers within a daily commute is 2 transfers (including transfers of individual car transport/public passenger transport in the case of using the Park and Ride (P+R) system, or transfers between regional public passenger transport and city public transport by transport). This number does not include possible transfers between individual public transport lines at the source or destination. Systems of a combination of individual and mass transport (P+R) and Bike and Ride (B+R) are particularly important in locations of a primarily resource nature (rural areas, satellite towns), wherever a non-negligible part of the population of the attractive district of a specific public stop of personal transport is more than a 500-meter walking distance from this stop. If we consider a walking distance of 1,500 m as the maximum limit of the attraction area, the justification of the P+R or B+R system depends on whether there are enough registered residents potentially willing to use such a system in the interval from 500 to 1,500 m of pedestrian access.

5. Design of lines in terms of efficient circulation of vehicles and their crews

In the process of searching for efficient routing and line stops, it is also necessary to take into account the maximization of the use of vehicles and their crews, in such a way that the greatest possible part of the circulation cycle of the vehicle (the number of minutes from the departure of the vehicle from the starting point of the line to the next departure of the same vehicle from of a certain point) consisted of the line service itself. This means that unproductive stoppages of vehicles and their crews at the end points of the line (or, in the case of rail transport, at any other points due to crossings, etc.) should be minimal, but sufficient to offset time losses from normal operational delays, actions associated with change direction of travel of the vehicle at the end point of the line. The decisive element here is the sum of the travel time from the start point of the line to the end point and the travel time from the end point to the start point (since the system travel time can be different for individual directions of the same line). This sum of travel times can reach 75 to 90% with an efficiently designed line:

- the length of the peak interval of connections (need for 1 vehicle/set to service the line),
- 2 times the length of the peak interval (need for 2 vehicles/sets to service the line),
- 3 times the length of the peak interval (need for 3 vehicles/sets to service the line).

Mandatory work breaks for the crews of public passenger transport vehicles can be determined at the time of the transport saddle, when a 2-fold connection interval compared to the peak time is assumed. Vehicle stops at one of the end points of the line then exceed 30 minutes (in the case of a 30-minute peak interval) or 60 minutes (in the case of a 60-minute peak interval).

6. Example of a procedure in real conditions

The framework procedure for designing functional layers and directional character of regional public passenger transport lines can be applied in practical conditions, as a rule, only to a limited extent. The historical development of the region, its topology, population concentration, social structure, transport habits, or traditional ties between specific locations come into play. Therefore, it is essential that the research team knows the given functional region as intimately and comprehensively as possible after all relevant aspects. Of course, this does not mean that the above-mentioned procedure should not be followed as much as possible by the research team. However, he should be able to deductively transfer his philosophy (thanks to a thorough personal knowledge of regional specifics) to real conditions.

Among the basic determinants of the resulting form of routing and functional layers of public passenger transport lines are factors such as the distribution of the population within the borders of the region, the topology of the region and the directional constellation of the transport network, the quality parameters of the road and railway infrastructure, the socioeconomic characteristics of individual settlements in the region, gravitational links - real and potential transport flows, competitiveness of public passenger transport (respectively integrated transport system) against individual automobile transport.

Figure S2 shows a fictitious example of the resulting routing design and functional differentiation of the lines, given the traffic network and settlement settings (divided into 4 categories):

- Number 1 indicates the seat of the 1st category (regional city), number 2 the seat of the 2nd category (district city), number 3 the seat of the 3rd category (other city or centre village) and number 4 the seat of the 4th category (ordinary village).
- The numbers in parentheses indicate the travel time along the entire length of the given line in one direction.
- Category A lines represent the supporting layer of the network of regional public passenger transport lines, connecting mainly the 1st and 2nd category locations.

- In the case of the A1 line, it is a zone service, thanks to which the limit of attractive daily commute to the residence of the 1st category (45-50 minutes) is shifted by several municipalities beyond the shown residence of the 2nd category.
- In the case of line A2, it is a normal express service (with a stop on the way only in the centre village), thanks to which the relevant 2nd category residence is within the daily commuting radius of the regional centre (1st category residence).
- Category B lines represent the final layer of the network of regional public passenger transport lines. These are lines that service all locations on the network in a one-stop manner. Lines of the end layer either connect to the lines of the carrier layer in direction or complement them simultaneously on sections with an accelerated mode of operation.

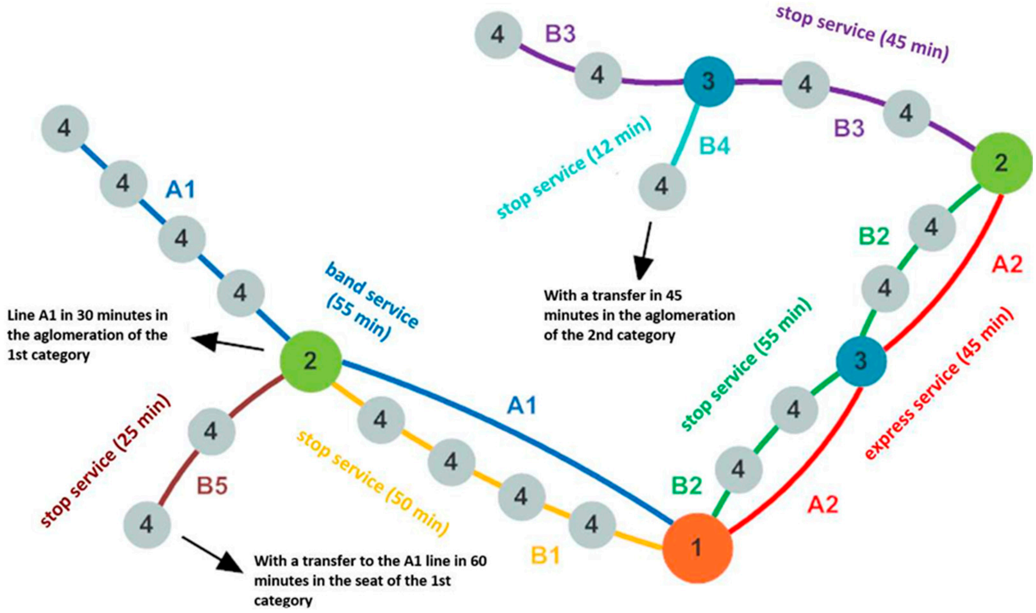

Figure S2: Example of design of routing and functional layers of public passenger transport lines. Source: authors, according to [18].