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Methodology for Designing a System of Public Passenger Transport in a Functional Region

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Abstract

Transport, as an object of research and design, is directly influenced by other functional components of the territory, it is caused by them, but at the same time it determines them in terms of limitations and development. A comprehensive approach to the design of transport systems involves a wide range of analytical and synthetic activities. Transport and territory are interrelated, while transport is one of the main factors defining the functionality of territorial structures. The development of transport systems brings greater availability of work, services, and leisure activities. The transport solution in the territory must be directed towards the adequate satisfaction of the transport needs, which are characterized by the intensity of the transport relations in the territory, depending on the time and quality of the relocation. The article presents a methodology for the design of regional public passenger transport lines, in accordance with the principles of sustainable mobility, supporting the competitiveness of public passenger transport and the efficient use of resources. The proposed methodology presupposes an already completed and processed analytical phase of the transport planning process and includes the impact of public passenger transport on the external environment. The methodology is applicable under the conditions of designing a completely new transport service system, as well as in the process of reorganizing existing transport systems, including rail and bus transport.

Keywords

public passenger transport, regional transport, transport lines

1 Introduction

When designing the transport system in each area, it is necessary to respect several principles, confirmed by the previous development of urban planning and spatial planning (the principle of openness of the system, the principle of integration of transport, the principle of hierarchy of nodes and lines, etc.). Despite their general validity, the main emphasis must be placed on the specific conditions of the area and the specific needs of its inhabitants. The economic and social maturity of the country is often the determining factor for the development of transport systems.

Respecting all these general principles, the biggest part of the problem of designing transport systems, buildings and means of transport is left to a particular design team (designer or team of designers), capable of combining exact transport, technical, economic, and ecological requirements with a natural feeling for nature, harmony, and composition of space (Bérczi et al., 2017). The following sequence of steps should be followed as a general procedure for solving transport problems in a city or region (Abramović et al., 2021):

- optimization of the functional layout of the city or region with the aim of eliminating unwanted transport at all levels,
- design and construction of new transport systems or their parts, or reconstruction of existing transport systems,
- organizational measures and transport management with the aim of optimizing the use of existing and newly created transport corridors,
- regulation and restriction of some types of transport.

When designing a new transport service technology, it is necessary to look for a solution that, with the minimum possible financial burden, will ensure a sufficient

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level of service to the region with adequate quality, safety, and reliability. A possible procedure is as follows (Šipuš and Abramović, 2017):

- determination of the transport network,
- assigning the size of transport flows to individual edges of the transport network,
- selection of modes of transport,
- assignment of individual types of transport to the edges of the transport network,
- determining the main transfer nodes and the location of the stops of the connections,
- creating a timetable.

Several studies have addressed the design of better public transport systems. The study by Bulíček et al. (2022) dealt with modelling of structure of public transport lines in the agglomeration of Pardubice. Nachtigall and Jerosch (2008) solved simultaneous network line planning and traffic assignment. Similar research was also carried out by Hartleb et al. (2023), and Borndörfer and Karbstein (2012). Ulahannan and Birrell (2022), Gkiotsalitis and Cats (2021), and Černá et al. (2023) dealt with the proposal of better public transport during and after the Covid-19 pandemic.

2 Public transport in a functional region

Traveling by public transport is essentially a series of movements and waits, where the relative importance of each such segment of the journey varies depending on the length of the journey and the nature of the waits.

The transport service system has a different spatial connection to the transport infrastructure. The service of the territory can be carried out peripherally or centrally, in passenger transport with different connection of individual car transport and public passenger transport systems. The transport service system must therefore be assessed simultaneously with the suitability of the transport infrastructure. Entry/exit points of public passenger transport are in the sources and destinations of transport or in the places of continuity of transport relations based on a traffic engineering assessment, considering the coordination of passenger transport (Gogola et al., 2021).

Transport within the functional region should form a unified system, coordinated from one center. To main, high-capacity lines of regional public passenger transport, it is advisable to use existing railway lines. The task of rail transport is to radially connect the region to its core (ideally, by ensuring regular operation) and at the same time to connect the region to the national and pan-European railway transport network (Goerigk and Schmidt, 2017). Bus transport should rather fulfill the function of connecting transport to such powerful railway lines or ensure comprehensive service of the region in less busy directions. It is also necessary to integrate individual transport into such systems - automobile, pedestrian, and bicycle (Gnap et al., 2023). Some of the most common basic network configurations are shown in Fig. 1.

Example A shows the concept of direct fast connections between selected points, without the possibility of transfers between lines (shuttle operation). Example B shows a grid concept of lines. The remaining examples represent networks of lines characterized by gravity towards the center. Example C represents a radial network and example D a diametric one. Example E illustrates the principle of tangential connections between lines within a radial or diametral network. Example F shows a combination of lattice and diametral mesh (Čelko et al., 2007).

Integrated transport is the way to increase the attractiveness of mass transport and improve its economy. It is a system solution for the mass transport of people in a pre-defined

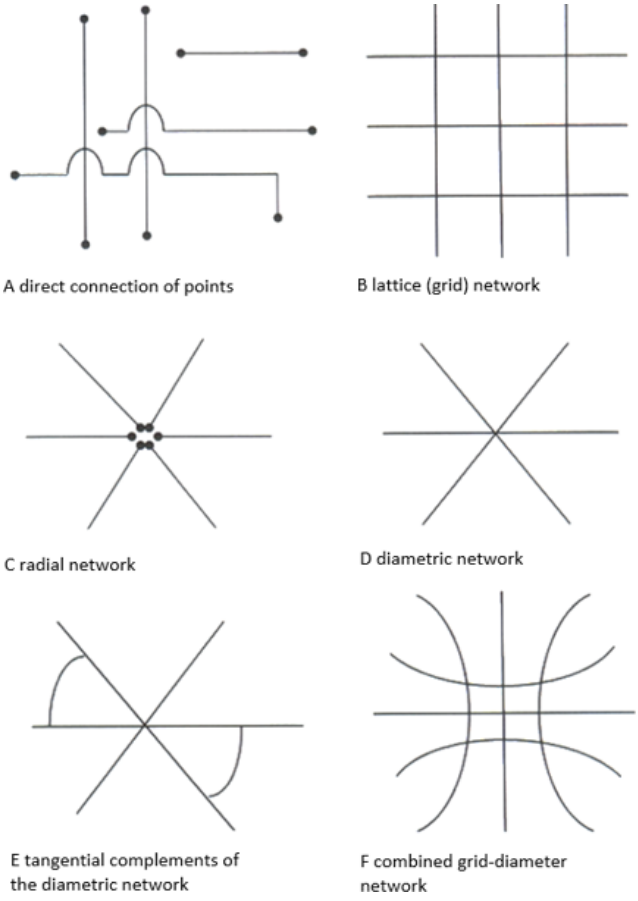

Fig. 1 Basic concepts of line networks in public passenger transport systems (Source: Čelko et al., 2007)

area. The basic principle of the integrated transport system is the mutually coordinated transport offer of all carriers involved in the integrated transport system in the entire functional region (Rybicka et al., 2018). The basic task is to offer competitive public passenger transport, which will divert the user from using individual car transport, which will lighten the road network and reduce the burden on the environment. A well-designed integrated transport system basically brings the following advantages for smaller towns and villages in the region (Gogola, 2015):

- improvement of the transport connection with the center of the region,
- improvement of traffic service at the local level,
- better availability of work and civic amenities,
- an increase in land prices in zones with high-quality service by public transport,
- increase in tourism,
- reduction of seasonal problems with individual car transport in tourist centers,
- reduction of unemployment of residents (thanks to higher mobility),
- increasing safety on roads (by reducing their traffic load),
- depopulation of towns and villages on the periphery of the region,
- more opportunities for leisure activities (transportation by public transport to recreation zones, as well as to cultural or sports events).

3 Methodology for designing a system of public passenger transport lines in the region

An important feature of the attractive transport service system of a region is the mutual continuity of the lines – the complementarity of individual segments of the transport network.

The methodology for designing regional public passenger transport lines considers the principles of sustainable mobility and the support of the competitiveness of public passenger transport. It is a methodology that assumes an already completed and processed analytical phase of the traffic planning process and includes exclusively its design phase. The design of public passenger transport lines requires knowledge of the transport behavior of the region's inhabitants, its causes and development forecasts. The very content of the methodology for designing the public passenger transport system in the region consists of the design of the routing of the functional layers of the lines in terms of the hierarchy of nodes and the mapping of the effects of public passenger transport on the external environment.

The route propose of functional layers of lines defines regional lines of public passenger transport in terms of the importance of resources and goals (from the point of view of demand and potential benefits), as well as defining functional layers of lines and effective intermodality (including division of labor with individual modes of transport). Mapping the effects of public passenger transport on the external environment represents a schematic description of the effects of various elements and determinants of the transport service system on the quality of the external environment. The purpose is to be aware of individual dependencies and their complexity, especially within protected areas, urbanized zones, tourism centers, interactions with other transport systems, or in supporting economically lagging regions.

3.1 Design of routing and functional layers of lines in terms of node hierarchy

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 predefined region. These dependencies are displayed using a source-destination matrix, or graphically through a network graph, where individual vertices (nodes) represent sources and destinations in the territory, while rated and directional edges show the direction and intensity of passenger transport flows. Fig. 2 shows the process of creating the routing design and functional layers of public passenger transport lines.

The ideal input is a complex traffic 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 of this methodology can be several variants of line management within certain parts (segments) of the transport network, e.g., if it is possible to ensure the connection of 2 centers on the network either by railway or bus line, the routes of which, however, are different due to the transport infrastructure, which subsequently affects the line service of intermediate settlements.

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

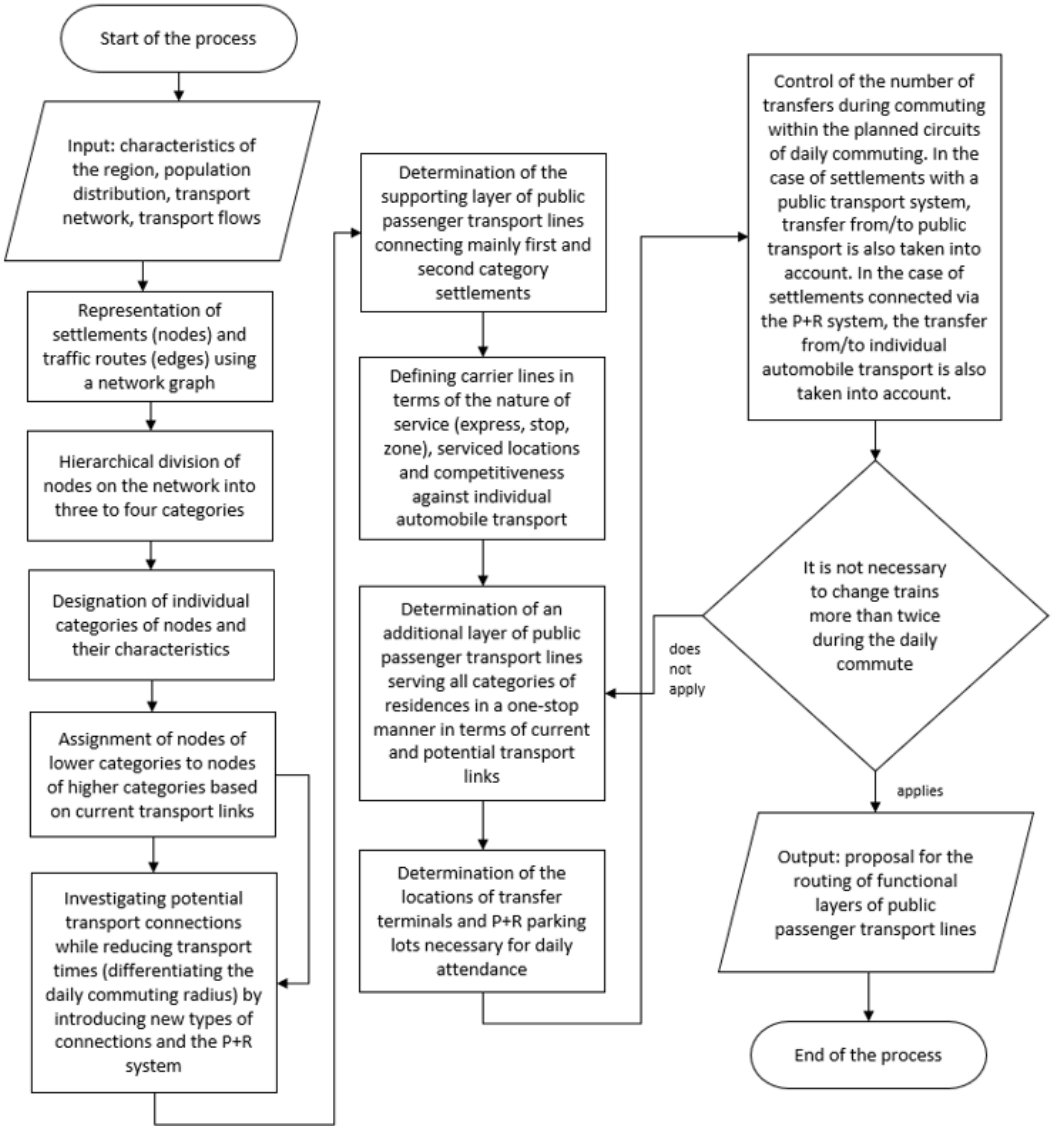

Fig. 2 The process of creating a proposal for routing and functional layers of public passenger transport lines (Source: authors)

departure of the same vehicle from it) consists of the line service itself.

3.2 Mapping the effects of public passenger transport on the external environment

As part of the assessment of broader relationships in the process of modeling the public passenger transport system, it is necessary to pay adequate attention to the impact of public passenger transport on the external environment. The aim is to maximize the positive and eliminate negative impacts of public passenger transport in this environment. In different environments, individual impacts of public passenger transport on the external environment have different meanings.

The importance of the effects of public passenger transport on the external environment is particularly evident when planning transport in protected natural areas (ecological and aesthetic effects), in urbanized zones (safety of residents, health, building development of settlements, barrier effect of railways), in tourism centers (aesthetic and economic impacts of transport), from the point of view of interactions with other types of not only personal transport (safety aspects, impact on the operation of other transport systems), or from the point of view of the state's declared effort to specifically support the development of economically lagging regions (benefits resulting from increasing the accessibility of regions and supporting the mobility of the population).

3.2.1 Ecological and hygienic effects of public passenger transport

One of the main arguments for supporting public transport is the protection of the environment and the health of residents. However, public passenger transport is also

a producer of emissions, noise and vibrations. For example, the production of noise and vibration is often more disturbing when using independent traction than it is in the case of individual automobile transport. The influence diagram in Fig. 3 shows the ecological and health impacts of public passenger transport.

The degree of negative ecological or health impact of public passenger transport on the external environment is primarily influenced by three types of decisions of the decision-making team within the transport-planning process, respectively competent authority:

- determining the route of the line,
- choosing a specific type and means of transport,
- determining the frequency of connections.

It is necessary to minimize the negative ecological and health effects of public passenger transport, especially in urbanized environments, in recreation zones and in protected natural areas.

3.2.2 The impact of public passenger transport on the socio-economic development of the territory

Increasing the mobility of residents in the form of an attractive offer of public passenger transport has an impact on the availability of (not only) work and services. Increasing the transport accessibility of smaller settlements within the region has an impact on the economic production in these settlements, the inflow of investments, and the tourist attendance of the region. The constellation and nature of public passenger transport lines (routing, availability, connection intervals, etc.) has an impact on the attractiveness of the territory, and thus also on its general socioeconomic development. Fig. 4 shows the effects of public passenger transport on the socioeconomic development of the territory.

The degree of positive impact of public passenger transport on the socio-economic development of the territory is primarily influenced by five types of decisions of the decision-making team within the transport-planning process, respectively competent authority:

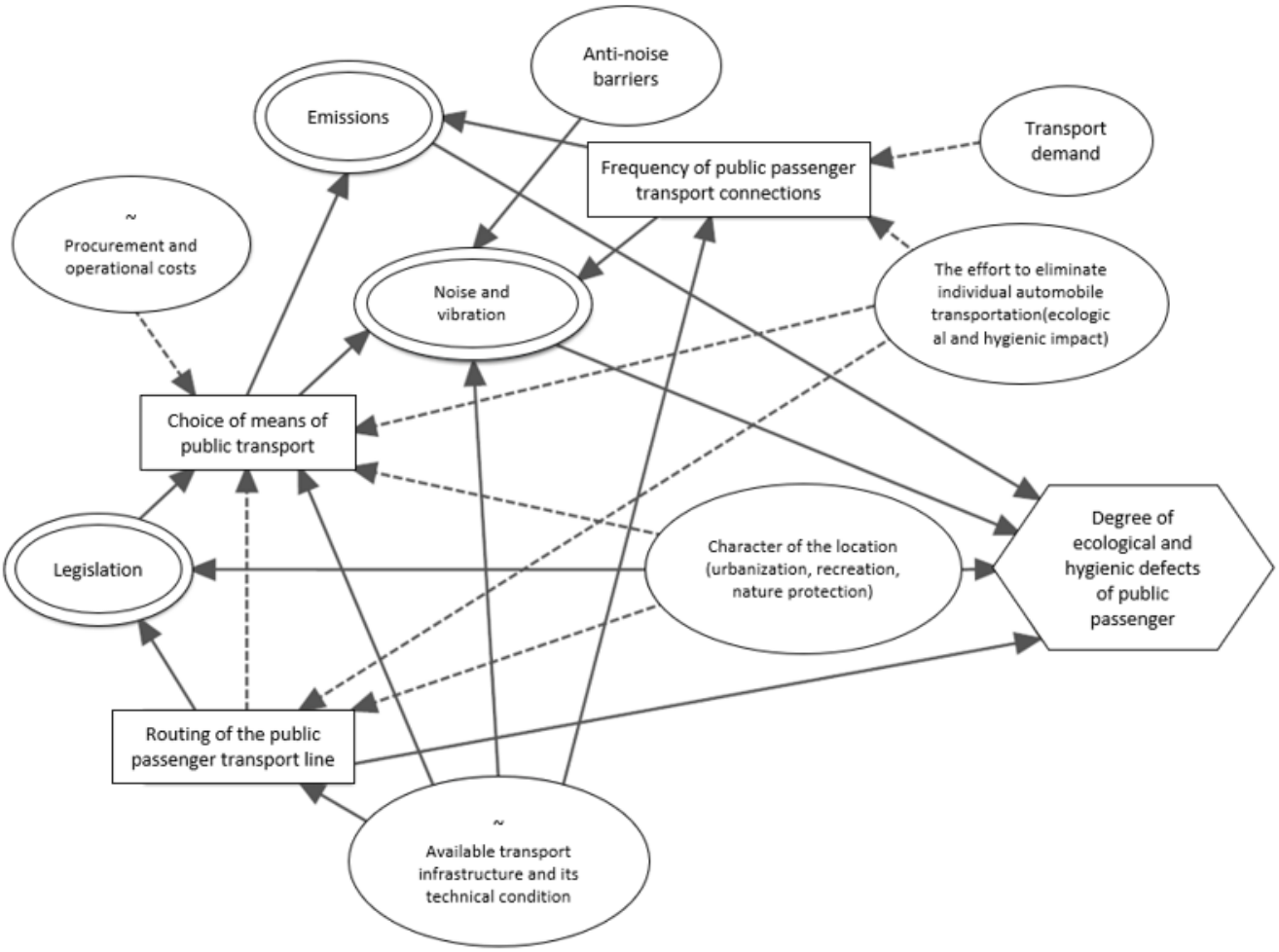

Fig. 3 Influence diagram of ecological and health impacts of public passenger transport (Source: authors)

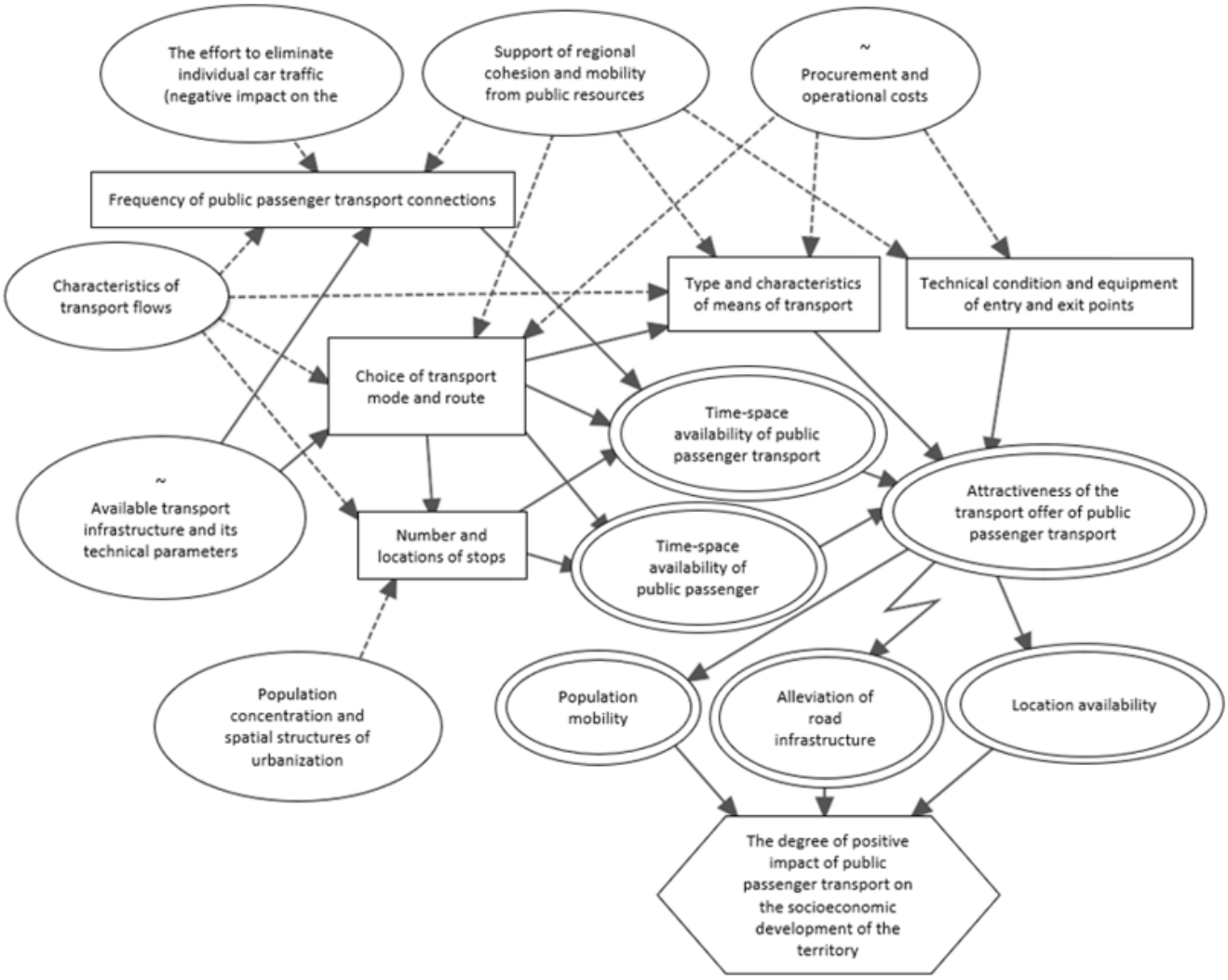

Fig. 4 Influence diagram of the influence of public passenger transport on the socioeconomic development of the territory (Source: authors)

- selection of the transport mode and route of the public passenger transport line,
- choosing a specific means of transport with specific characteristics,
- determining the locations and number of stops,
- defining the technical form and equipment of stops.

3.2.3 The influence of public passenger transport on the safety and operation of other transport systems

In our conditions, regional public passenger transport practically always shares the transport infrastructure with other types of transport (individual car transport, road freight transport, rail freight transport, urban public transport, long-distance public passenger transport and others), thanks to which its form and nature of operation affects the safety and smoothness of other infrastructure users. In addition to shared infrastructure, level crossings are also an important factor in the flow and safety of other traffic processes. The degree of restriction of the flow and safety of other traffic processes due to the influence of public passenger transport is mainly influenced by two types of decisions within the traffic planning process:

- selection of the transport mode and route of the public passenger transport line,
- determining the frequency of connections.

The impact of public passenger transport on the safety and operation of other transport systems is shown in Fig. 5. An example can be the concentration of passenger traffic on busy sections of the railway network – with a negative impact on the operation of freight rail transport.

3.3 An example of a procedure in real conditions

The above-described framework procedure for designing functional layers and the directional nature of regional public passenger transport lines can be applied in practical conditions, as a rule, only to a limited extent.

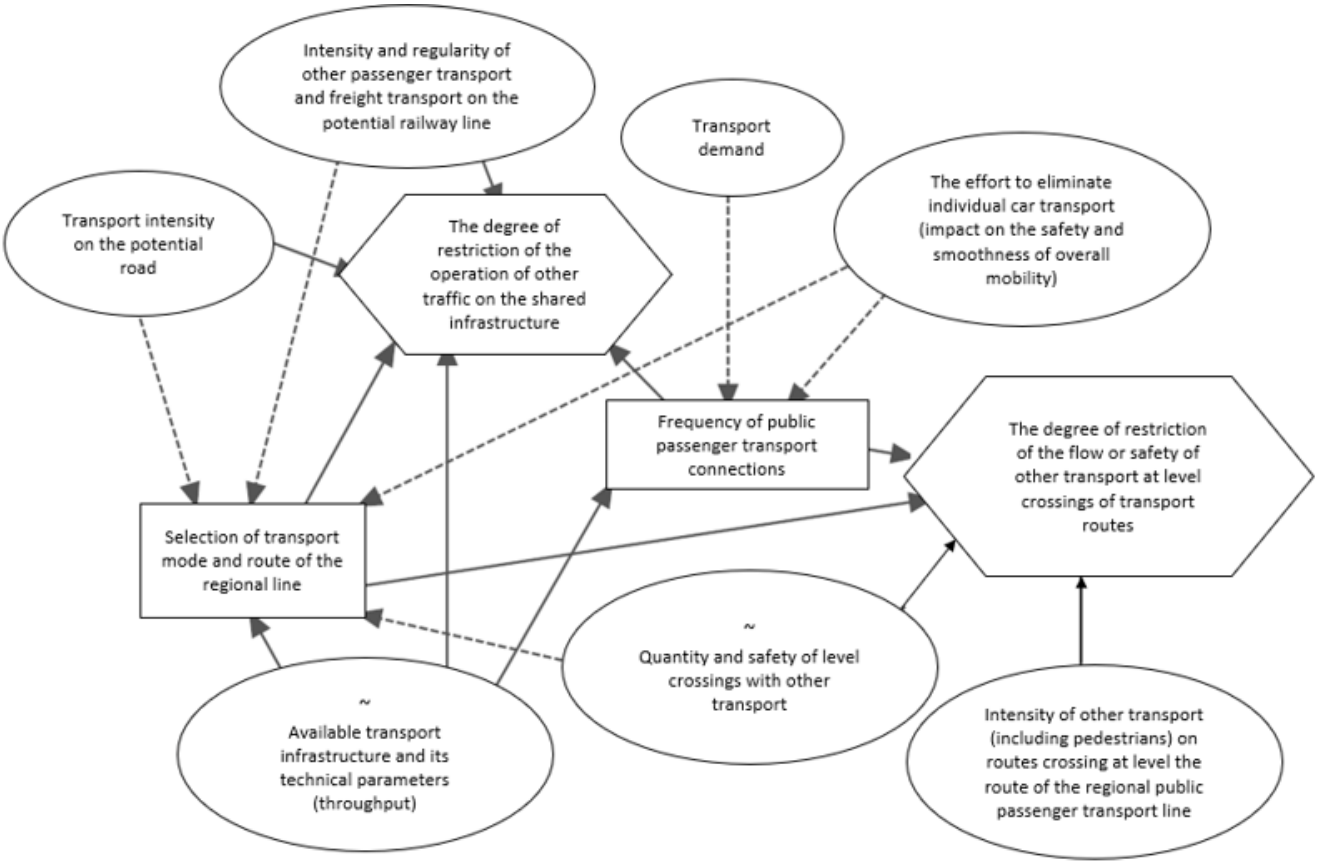

Fig. 5 Influence diagram of the influence of public passenger transport on the safety and operation of other transport (Source: authors)

Fig. 6 shows a fictitious example of the resulting design of the directional line and the functional differentiation of the lines, with the given constellation of the transport network and settlements (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 center 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 lines of public passenger transport, mainly connecting 1st and 2nd category settlements. In the case of the A1 line, it is a zone service, thanks to which the limit of an 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 center village), thanks to which the relevant 2nd category residence is within the daily commuting radius of the regional center (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.

4 Conclusion

In the field of designing public passenger transport lines for the purpose of regional transport, there is no comprehensive methodological procedure in Slovakia. Also, from the position of the Ministry of Transport of the Slovak Republic, uniform standards of regional transport service, which could be adhered to by those ordering public passenger transport, were not adopted. In practice, different customers prefer different criteria when creating public passenger transport systems, while the final form of the system is usually defined by a compromise between the ideas and experiences of carriers, public passenger transport customers and relevant political leaders.

The methodology for designing public passenger transport lines in a region establishes a comprehensive framework procedure for the modeling of line service in the region, following on from the outputs of transport, socio-economic and environmental analyzes and forecasts of the development of the region under consideration. This

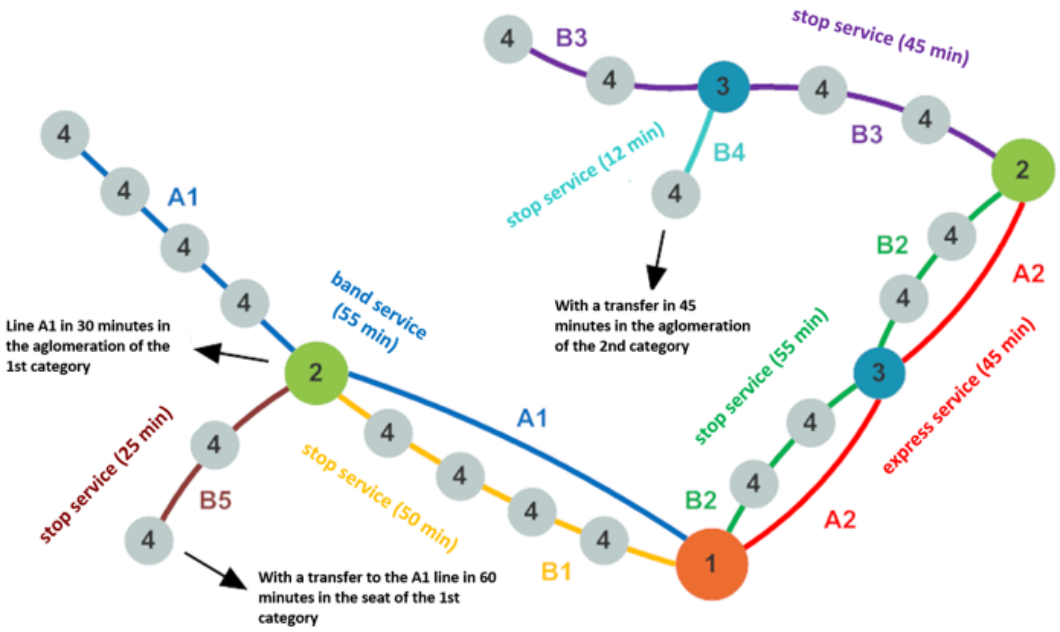

Fig. 6 A hypothetical example of routing design and line functional layers (Source: authors)

methodology is characterized by the fact that it can be used exclusively in the environment of integrated transport systems, as it assumes one customer of public passenger transport, as well as uniform tariff conditions for all types of public passenger transport.

The methodology considers the specific infrastructural, urban, demographic, economic, natural, and cultural attributes of the addressed region, or its individual parts and is a superstructure to the traffic service standards (as we know them in Slovakia and in the surrounding countries), but it is not conditioned by their existence. It perceives the issue from three perspectives, namely from the point of view of route routing, from the point of view of external influences of public passenger transport and from the point of view of traffic service systems on the lines. The methodology gives relatively wide possibilities of subjective influences, which is why it is necessary to pay attention to the professional composition of the expert group of solvers, and it is applicable in any functional region, and its user should ideally be a regional transport authority.

It is important to realize that public passenger transport is a tool for the socio-economic development of the territory. Therefore, it is first necessary to define at the expert and political level what the given region should look like (functionally, economically, socially) and then to set up a sustainable model of the transport system, supporting the development of the region in a defined direction, considering the principles of sustainable mobility and the support of competitive public passenger transport.

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