

Organizational and economic mechanism of the automatic underground train operation system



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ABSTRACT

This work deals with the provision of underground, as one of the main modes of public transport, with automated control systems, in particular the provision of automated train management. It defines that the underground is one of the most progressive modes of transport, which is related to its environmental safety, comfort, and speed of movement, as this mode of transport does not intersect with other transport and pedestrian routes, which excludes traffic blocks. Underground is an important element of urbanized spaces, for it serves large passenger traffic. The article presents an algorithm for the creation of an automated control system for the underground train system. Based on this algorithm, a model of building an organizational and economic mechanism for automation of control systems has been developed. The diagram of organizational and technical implementation of the automated system of underground train management is presented. An economic analysis of the effectiveness of the application of the automated control system of underground trains was carried out. The recoupment on the acquisition and installation of automation systems is very high. The application of the automated system will increase the capacity of the underground by optimizing the traffic schedules, which will contribute to increasing its profitability. It is also useful to determine the reduction of electricity consumption due to the change in the dynamics of acceleration and braking systems, which is important, as the underground is a powerful enterprise. In the future, a promising direction is to streamline the coordination of train schedules and other modes of land public transport.

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1. Introduction

In today's world, electric transport plays an important role. It is called transport of the future, which is primarily related to the environmental efficiency of its use. With the constant growth of traffic flow, which is due to the growth of the urban population and the attraction of the urban population to transport attractive areas (i.e., having good transport accessibility), the issue of optimization of transport is acute. For large metropolitan cities of Ukraine, one of the main

modes of transport carrying more passengers in cities such as Kyiv or Kharkiv is the underground. The prospects of underground development as the main mode of transport are related to a number of factors, for example, this mode of transport does not create traffic blocks (one of the main problems of transport flows in modern conditions of development of metropolitan cities), its independence from weather conditions and reliability, as a result—clear movement of trains on schedule and speed of passenger movement. However, the problem of management of underground enterprises and its main component—automation of transport control processes, which is closely connected with solving problems of energy efficiency, transport safety, clear observance of traffic schedule and speed rate, an increase of economic efficiency of this mode of transport remains an urgent challenge (Lukasevych-Krutnyk, 2020).

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The works of many domestic and foreign scientists are devoted to the development and implementation of automated control systems in transport in order to increase economic efficiency, environmental compatibility, safety, and comfort of passenger transportation. In particular, [Abed \(2010\)](#) proposed an analysis of European experience in traffic flows management systems to ensure cost-effectiveness and clear compliance with transport schedules. The issues of passenger safety conditions in the implementation of automated control systems in transport were considered by [Davis \(2010\)](#), the author defined the conditions of automatic protection in the implementation of transportation processes. [Faggini and Parziale's \(2012\)](#) examined the economic aspects of transport provision, taking into account the development of methods for rationalizing constant and variable production costs. [Zhukovytsky \(2017\)](#) considered the transport problem of the development of models of automation of information control systems in transport. A number of authors ([Liu et al., 2011](#)) analyzed and carried out modeling of optimization processes of automated control systems in order to increase their safety and ensure economic efficiency. [Skalozub and Osovik \(2014\)](#) were engaged in the development of intelligent systems for the optimization of various parameters of traffic flows.

However, despite the authors' considerable attention to the issue of optimization of transport processes due to the rapid development of information technologies and the relevance of the issue of modernization and IT-support of automated control systems in transport, the problems of improving the efficiency of the organizational and economic component of transport automation in the underground remain unresolved ([Sheludchenko et al., 2019](#)).

The purpose of the article is to develop organizational and economic mechanisms for the automation of the underground train traffic system. The object of the study is the process of organizational and economic support of underground trains. The subject of the study is public utilities–undergrounds of cities of Ukraine.

In order to achieve this purpose, the authors set and solved the following objectives:

- Analysis of the technical component of the underground train system;
- Description of the algorithm of the underground train automatic control system;
- Development of an economic and mathematical model for automation of underground train traffic processes;
- Development of proposals for the implementation of the organizational and economic mechanism of automatic train operation.

2. Description of the main features of underground transport

The main feature of the underground, as a mode of public transport, is its engineering separation from flows of other modes of transport and passenger traffic. This feature of underground avoids a number of problems faced by other modes of transport, such as traffic blocks, dependence on weather conditions, and coordinated work of specialized transport, such as road cleaning in winter. In addition, in terms of domestic specificity, the underground has an advantage over other modes of transport, which face poor road surface quality, which has a negative effect on road flows, failure to comply with traffic regulations by drivers, which often leads to accidents and traffic complications, including public traffic ([Abed, 2010](#); [Davis, 2010](#)).

Due to such features, the underground is characterized by high train speed (up to 80 km/h), clear schedule, high degree of traffic, and passenger safety, as it is located outside the street transport network. The underground has very high passenger capacity, allows to solve transport problems in widely populated areas quickly where new underground stations are being built. In general, the management of transport organization in the underground can be characterized by the following factors determined by the results of the analysis of world experience ([Fig. 1](#)).

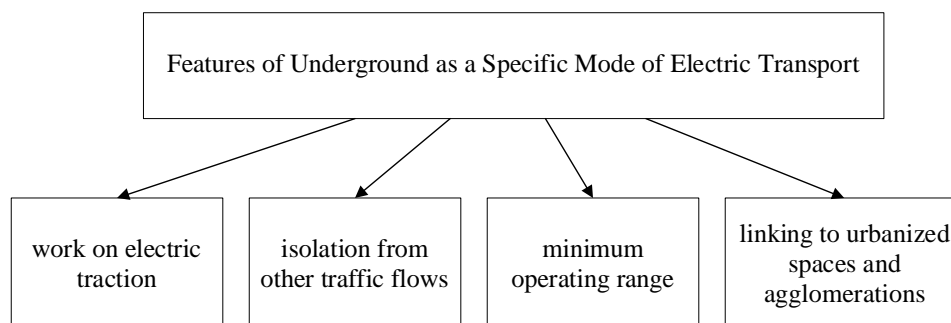


Fig. 1: Specific features of the underground as a mode of transport

[Fig. 1](#) shows the specific features of the underground. There are a number of technical characteristics among them. One of them concerns the use of electricity as traction in transport and the need to calculate electricity costs in the context of

the introduction of a new electricity market in Ukraine. The underground activities depend significantly on the cost and conditions of supply of electricity both technically and economically. So, the high percentage of the electricity cost in the cost of

transportation by underground is one of the key factors to be taken into account when building economic models for the development of this mode of transport. Due to isolation from other traffic flows, as mentioned above, the underground has a high degree of safety and a minimum deviation from the transport schedule. Such indicators contribute to the high comfort and reliability of this mode of transport for passengers. The minimum operating range allows passengers not only to clearly calculate the movement time but also to minimize the travel time. Thus, the underground can carry large passenger

traffic during the day. It is due to the possibility of transportation of significant passenger traffic and isolation from other modes of transport, underground services are very relevant in large cities with heavy road traffic and overpopulation. So, the development of the underground is one of the tasks of “smart” urbanization (Bakulina et al., 2019).

Turning to the organizational component of the automation of the process of transportation of underground passengers, it should be noted that to date the operation of each train is carried out according to the following diagram (Fig. 2).

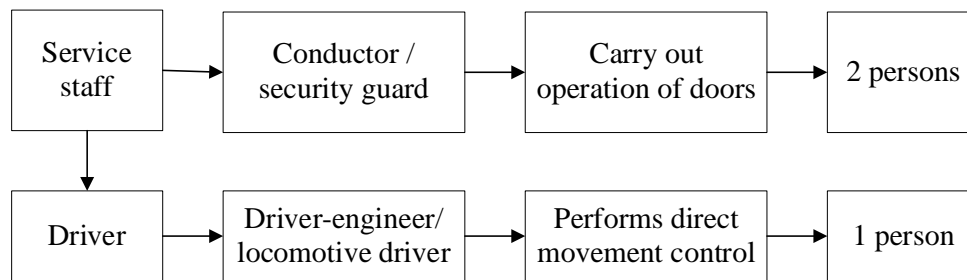


Fig. 2: Organizational component of maintenance of one train (Faggini and Parziale, 2012)

Optimization and automation of production processes contributed to the reduction of maintenance personnel from 2 to 1 person, because of the placement of mirrors and closed-loop TVs. Automation of train processes was started in London in 1968. For the first time, automated train traffic control systems were used in the London Underground. The automated GoA2 system assumed the following driver functions (Zhukovytsky, 2017):

- Budge of the train;
- Gathering the speed to a certain limit;
- Automatic stop according to platform boundaries.

The following functions remained for the driver of such a train (Zhukovytsky, 2017):

- Analysis of rail centers and platform information;
- Control of movement systems and correction of automatic actions in case of emergency;
- Closing the doors.

The use of semi-automatic train traffic control systems is due to the need to ensure a high level of underground safety and to respond quickly to possible abnormal situations where train workers, if necessary, to evacuate, help passengers get out of underground tubes. It is for these reasons that a number of undergrounds of the world do not pass to complete automation of train control processes.

3. Analysis of the application of automated control systems in order to increase the economic effect of underground operation

Today, in conditions of decreasing the cost of development and implementation of automated control systems and information systems in transport, improvement of technological

developments of automation, it is useful to study the issue of application of automated control systems in order to increase the economic effect of underground operation in the world and, in particular, in Ukraine. The system of “unmanned trip”, based on the operation of elevators, makes it possible to operate without the train crew at all, ensuring its movement, stops, acceleration/speed reduction, door opening/closing, and actions in emergency situations automatically (Liu et al., 2011). The diagram of process automation of traffic management on the algorithm given above is submitted in Fig. 3.

The algorithm of automated traffic management of the underground is as follows:

- Step 1: Registration of car numbers in the head car–determination of the number of cars, their design features, type, and other technical characteristics using car devices–radio tags.
- Step 2: Analysis of distance and time of route–determination of run time from station to station and the whole route, determination of distances from the first car and the first stop of this car.
- Step 3: Data entry into system memory–creation an automated control model for a particular section of a road.
- Step 4: Data centralization–data transmission to the central dispatching control system for analysis of information and development of further correcting impacts or train release to the line (Navarro et al., 2019; Chernenko et al., 2020).

We will determine the number of advantages of this system of automated traffic control in the underground:

- The automated train traffic system is as economic as possible;

- The system helps to provide automatic control of car-mileages, their depreciating and amortizing, which is necessary for rational maintenance and repair of railway equipment;
- The system provides a high level of traffic safety;
- The system ensures clear observance of schedules and intervals.

Thus, the basis of the formation of the automated underground train system is automatic control systems based on two elements (Skalozub and Osovik, 2014):

- Problem formulation for the network:
 - Select the type of network
 - Analysis and training
- Network link formulation:
 - Input data introduction
 - Define output parameters

The formation of the automated train control system network can be described using a number of models (Fig. 4).

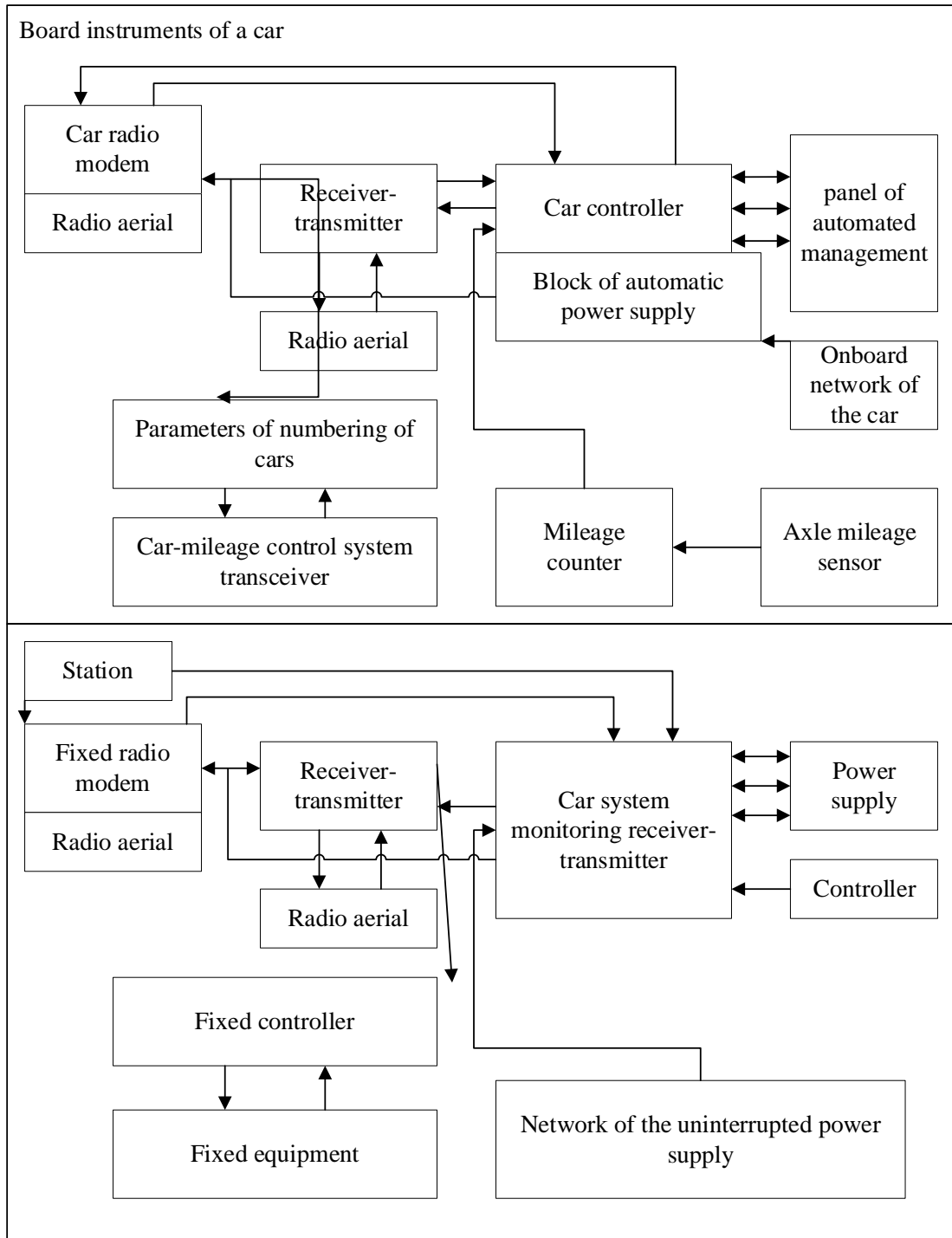


Fig. 3: Diagram of process automation of traffic management (Skalozub and Osovik, 2014)

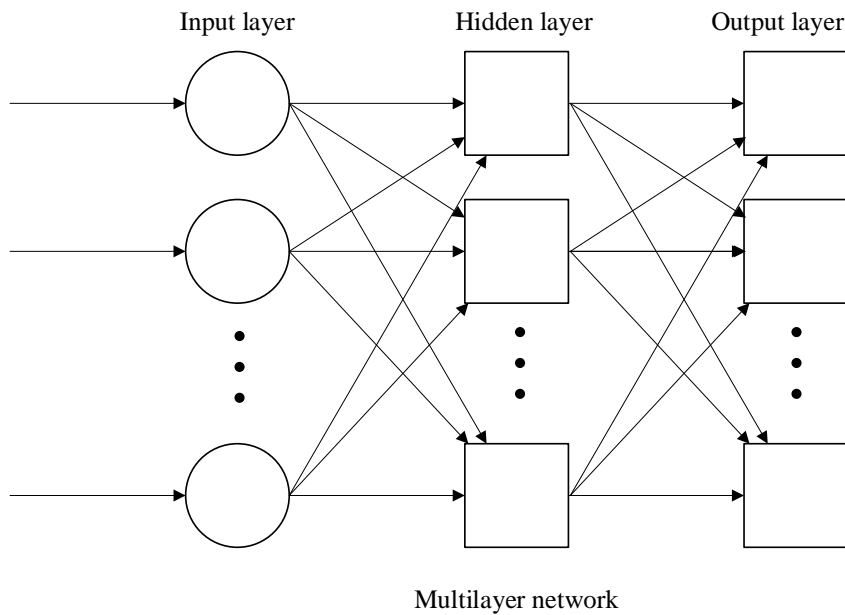
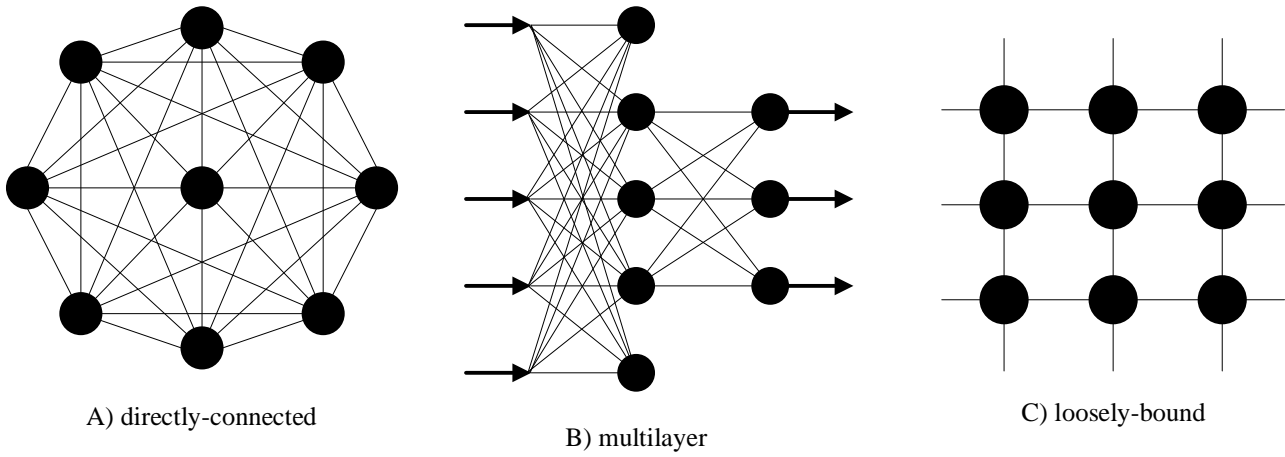


Fig. 4: Diagrams of formation of the automated train control system network (Faggini and Parziale, 2012; Zhukovytsky, 2017)

The question of choosing an automated network is usually multi-factorial, hence the best option from the models presented in Fig. 4 is a multilayer, which comprises various elements of the control system overlaid in “layers” into a single automated transport control system. The multi-layer model of automated control involves solving a wide range of tasks: start, stop, acceleration, information analysis, signal processing, observing timing and distance limits, control, prevention and elimination of emergency situations, forecasting, and the like (You et al., 2019; Africa et al., 2017; Naghiyev et al., 2017; Gaspari et al., 2019).

In order to build a model of automated control of underground trains, we will determine the interdependence of factors. Let X be the input information parameter, then B is the output parameter of the system responding to variable X. To predict the use of the automated transport control model in the underground, we define X as the parameters of the controlled object, and B as the code, which is determined by the current state of the

parameters of the controlled object. (X) and ensures appropriate system response (management adjustments) according to input parameters. Parameters X may include time frames, distances, etc. So, in a general view the automated transport control model in the underground can be presented in the following form (Eq. 1):

$$\{(X^k, Y^k), k = 1 \dots N\}, \tag{1}$$

where k=1, 2, ..., N is units in the sample. The following formula is proposed to calculate the integral indicator of the assessment of the automated transport control model of the underground (Eq. 2):

$$\frac{mN}{1+\log_2 N} \leq L_w \leq m \left(\frac{N}{m} + 1 \right) (n + m + 1) + m, \tag{2}$$

where n is the dimension of an entrance signal; m is the dimension of an output signal; N is units in the sample.

The proposed model of the automated control system of underground trains greatly simplifies the organizational control system, because it excludes the human factor and reduces the number of personnel involved to ensure the movement of trains, thus ensuring economic effect.

The economic effectiveness of implementing an automated control system can be calculated by analyzing the cost of installing such a system, saving costs, and analyzing the current costs of underground operations. We will calculate on the basis of averages for Ukrainian underground.

Input data: the cost of the offered system–35.000.000 UAH, the cost of service of 1km of lines a year is 34.285.000 UAH a year., payment of the automated system installation makes 40% of its cost –14.000.000 UAH, it is also necessary to consider reduction of expenses on the compensation of employees, who will be replaced with ACS, taxes and social payments of 30.000 UAH a year. So, you can calculate the following:

$$\frac{34285-30}{35000+14000} = 0.699 \approx 0.7.$$

Thus, the economic efficiency of the project will be realized in 7 months. In addition to the economic effect, it is necessary to note the improvement of the level of comfort of passenger transportation, the improvement of transport safety, and the possibility to improve the system of other financial and economic indicators, for example, on demolition and amortization of equipment, trains and rail and tunnel facilities, automation of passenger traffic calculations, etc., which together will give an additional economic effect (Berger et al., 2018; Cho et al., 2018; Feng et al., 2017).

4. Conclusion

Thus, having analyzed the technical component of the underground train system, the article provided a number of proposals. Indicators of efficiency, comfort, and safety of passengers, as well as possibilities to provide automation of information processing and analysis processes defined as important aspects of ensuring an effective underground control system. Existing automated control systems in transport allow defining a multi-factor model which is analyzed in the article, as input parameters of the control system. Parameters of incoming information and criteria for determining initial information of this system are proposed. Having carried out the description of the algorithm of the system of the automatic running of the underground trains, an economic and mathematical model of automation of the processes of movement of the underground trains and prospects of introduction of the organizational and economic mechanism of automatic train operation to ensure the economic effect, increase comfort and safety of transport, as well as the creation of conditions for automation of other technical and economic

processes on the basis of the developed model was designed.

The application of the automated system will increase the capacity of the underground by optimizing the traffic schedules, which will contribute to increasing its profitability. Also, in the future, it is useful to determine the reduction of electric power consumption due to the change in the dynamics of acceleration and braking systems, which is important, as the underground is a powerful enterprise. In the future, a promising scientific and applied direction is the rationalization and coordination of underground train schedules with those of other modes of public land transport.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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