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INFORMATION SYSTEM FOR DISPATCHERIZATION OF THE TERRITORIAL MUNICIPAL ELECTRIC TRANSPORT

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Анотація. *Стаття присвячена актуальній проблемі розвитку великих міст – підвищенню якості обслуговування населення електричним муніципальним транспортом та вирішенню цієї проблеми шляхом інформатизації системи управління. В даний час для підтримки роботи диспетчерських служб широко використовуються різні інформаційні системи. У статті надано огляд таких систем. Показано, що диспетчерам у режимі реального часу надаються дані про технічний стан і стан транспортних одиниць на маршруті. Таким чином, основним засобом забезпечення якісної роботи міського транспорту диспетчерськими службами є складання графіків руху на основі деяких статистичних даних і евристик, моніторинг виконання цього графіка і прийняття рішень на основі цих даних. При цьому дані про поточне значення пасажиропотоку не відомі і не враховуються. Пасажиропотік – величина складної природи, поточне значення якої може істотно відрізнятися від передбаченого графіком руху. У статті наведені дані модельних досліджень на реальних даних (для м. Харкова). Показано, що в великих містах імовірність відмови пасажирові в перевезенні може бути критично великою навіть при невеликих відхиленнях заповнення і інтервалів від значень, передбачених графіком руху транспорту. Запропоновано концепцію інформаційної системи, яка в режимі реального часу візуалізує на екрані диспетчера не тільки положення, але і ступінь завантаження транспортних одиниць на маршруті. Пропонується визначати заповнюваність транспортного засобу щодо потужності, споживаної електродвигунами під час руху. На простій моделі показано принципову можливість такого підходу. Також зазначено, яким чином ця модель може бути вдосконалена. Істотним для практичної реалізації системи є і те, що сучасні трамваї оснащені всіма необхідними пристроями: спідометром, нахилометром, ваттметром і GPS-датчиками. Наводяться основні принципи побудови архітектури такої інформаційної системи. Поточні дані приладів зчитуються і відправляються на сервер для обробки. Оброблені дані поділяються на два потоки. Один потік призначений для візуалізації ситуації на маршрутах у режимі онлайн на моніторі диспетчера. Інший потік являє собою дані, які передаються в репозиторій для зберігання і подальшої обробки.*
Ключові слова: *інформаційні системи, інформатизація управління міським електротранспортом, хмарні технології, рухомий склад, диспетчеризація.*

Аннотация. *Статья посвящена актуальной проблеме развития крупных городов – повышению качества обслуживания населения электрическим муниципальным транспортом и решению этой проблемы путем информатизации системы управления. В настоящее время для поддержки работы диспетчерских служб широко используются различные информационные системы. В статье дан обзор таких систем. Показано, что диспетчерам в режиме реального времени предоставляются данные о техническом состоянии и положении транспортных единиц на маршруте. Таким образом, основным средством обеспечения качественной работы городского транспорта диспетчерскими службами является составление графиков движения на основе некоторых статистических данных и эвристик, мониторинг выполнения этого графика и принятие решений на основе этих данных. При этом данные о текущем значении пассажиропотока не известны и не учитываются. Пассажиропоток – величина сложной природы, текущее значение которой может существенно отличаться от предусмотренного графиком движения. В статье приведены данные модельных исследований на реальных данных (для г. Харькова). Показано, что в крупных городах вероятность отказа пассажиру в перевозке может быть критически большой даже при небольших отклонениях заполнения и интервалов от значений, предусмотренных графиком движения транспорта. Предложена концепция информационной системы, которая в режиме реального времени визуализирует на экране диспетчера не только положение, но и степень загрузки транспортных единиц на маршруте. Предлагается определять заполняемость транспортного сред-*

ства по мощности, потребляемой электродвигателями во время движения. На простой модели показана принципиальная возможность такого подхода. Также указано, каким образом эта модель может быть усовершенствована. Существенным для практической реализации системы является и то, что современные трамваи оснащены всеми необходимыми устройствами: спидометром, наклонометром, ваттметром и GPS-датчиками. Приводятся основные принципы построения архитектуры такой информационной системы. Текущие данные приборов считываются и отправляются на сервер для обработки. Обработанные данные делятся на два потока. Один поток предназначен для визуализации ситуации на маршрутах в режиме онлайн на мониторе диспетчера. Другой поток представляет собой данные, которые передаются в репозиторий для хранения и дальнейшей обработки.
Ключевые слова: *информационные системы, информатизация управления городским электротранспортом, облачные технологии, подвижной состав, диспетчеризация.*

Abstract. *The paper deals with the topical problem of the large cities development – to improve the quality of service for the population by electric municipal transport and to solve this problem by informatization of the management system. Currently, various information systems are widely used to support the work of dispatch services. The paper provides an overview of such systems. It is shown that dispatchers are provided with real-time data on the technical condition and position of transport units on the route. Thus, the main means of ensuring the high-quality work of urban transport by dispatch services is the drawing up of traffic schedules based on some statistical data and heuristics, monitoring the implementation of this schedule and making decisions based on these data. At the same time, data on the current value of passenger traffic are not known and are not taken into account. Passenger traffic is a value of a complex nature, the current value of which may differ significantly from the provided traffic schedule. The paper provides data of model studies on real data (for Kharkiv city). It is shown that in large cities the probability of denied boarding can be critically high even with small deviations in occupying and intervals from the provided values by the traffic schedule. The concept of an information system is proposed, which in real time visualizes on the dispatcher's screen not only the position, but also the degree of loading of transport units on the route. It is proposed to determine the occupancy rate of the vehicle by the power consumed by the electric motors while driving. The fundamental possibility of such approach is shown on the example of simple model. It is indicated how this model can be improved as well. It is essential for the practical implementation of the system that modern trams are equipped with all the necessary devices: a speedometer, an inclinometer, a wattmeter and GPS sensors. The basic principles of building the architecture of such an information system are given. The current data of the devices is read and sent to the server for processing. The processed data is divided into two streams. One stream is intended for online visualization of the situation on the routes on the dispatcher's monitor. Another stream is data that is transferred to the repository for storage and further processing.*
Keywords: *information systems, informatization of urban electric transport management, cloud technologies, rolling stock, dispatching.*

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1. Introduction

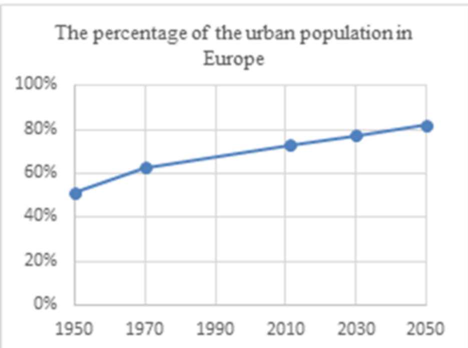

Figure 1 – The dynamics of urban population growth in Europe

Urbanization and the rapid pace of urban growth – a natural consequence of the development of post-industrial society in the context of globalization. Fig. 1 shows the data of the United Nations about increase the share of Europe's urban population in the past decade, and the forecast for the next 30 years [1].

According to the same UN department, Ukraine is a typical representative with 69% in 2018 and with a forecast the growth to 78% by 2050, despite a slight decrease in population. Thus, all the problems associated with these processes are fully characteristic of Ukraine.

«The city is a tool of labor» – so figuratively Le Corbusier defines the city in his monograph «Urban planning» [2]. Also, in this book, he formulates the basic principles that underlie modern ideas about the creation and development of cities. In particular, according to the instructions of Le Corbusier, for the effective operation of the city as a living environment and human activity, the pace of development of transport should be ahead of the pace of development of the city.

Kharkiv city electric transport [3] is developed much better than the subway [4] (Figs. 2, 3).

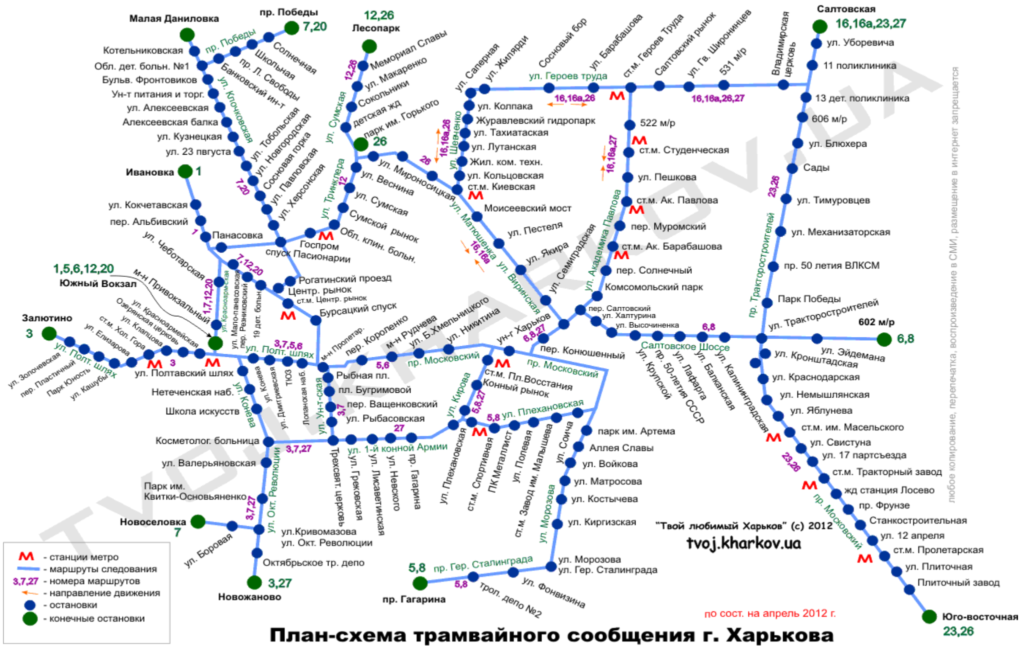

Figure 2 – Tram routes in the city of Kharkiv

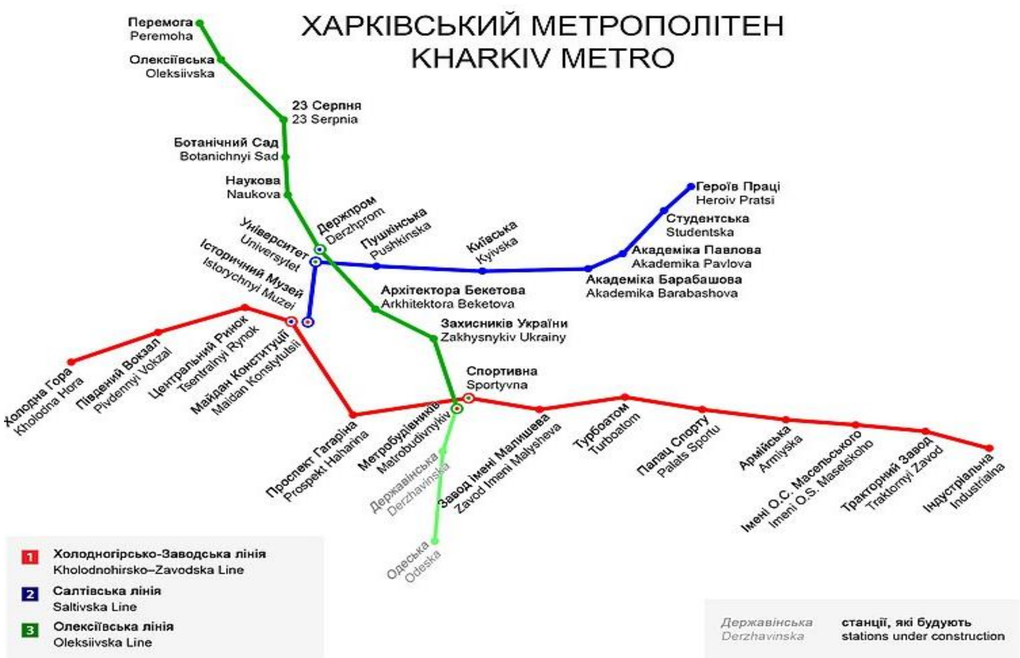

Figure 3 – Subway scheme in the city of Kharkiv

Moreover, the fare in electric vehicles is significantly less than in the subway (in 2019, 30% less).

Despite this, in the last decade there has been an increasingly noticeable negative trend in the volume of transportation by ground electric vehicles. According to the State Statistics Service for 2018, for example, trolleybuses were transported 131,8 million and trams 108,1 million passengers. During the same time, 223 million passengers used subway. Thus, the total volume of ground electric transportations decreased by 2,2% compared to 2017.

The main conclusion is that the main reason is the lower quality of passenger service by urban electric transport and the development of this type of transport is an urgent task for the development of a metropolis.

2. Information systems in urban transport management

Informatization of all processes in the management of modern urban transport is one of the most effective ways to improve the quality of work of this structure.

Today, all megacities use transport management information systems (TMIS), which include various geolocation services (GPS, etc.) to control the operation of transport in real time.

TMIS can be divided into two types: universal and specialized, designed specifically for urban transport.

Universal TMIS are designed based on the ability to dispatch different types of transport (public and private, freight and passenger, buses, taxis, etc.). The universality of these systems is determined mainly by the following:

• Software solutions are created for all popular OSs.
• Support for a large number of protocols and services.
• Unlimited number of transport units on the route.
• The ability to integrate into this service a large number of systems of a specific user or vehicle.

Sufficiently complete information about such systems can be found on the sites [5] and [6]. As a typical example of such systems, one can consider the service «BaseRide» [7].

Fig. 4 shows a screen of this system with information about vehicles and their routes, including data from vehicle systems integrated into the service.

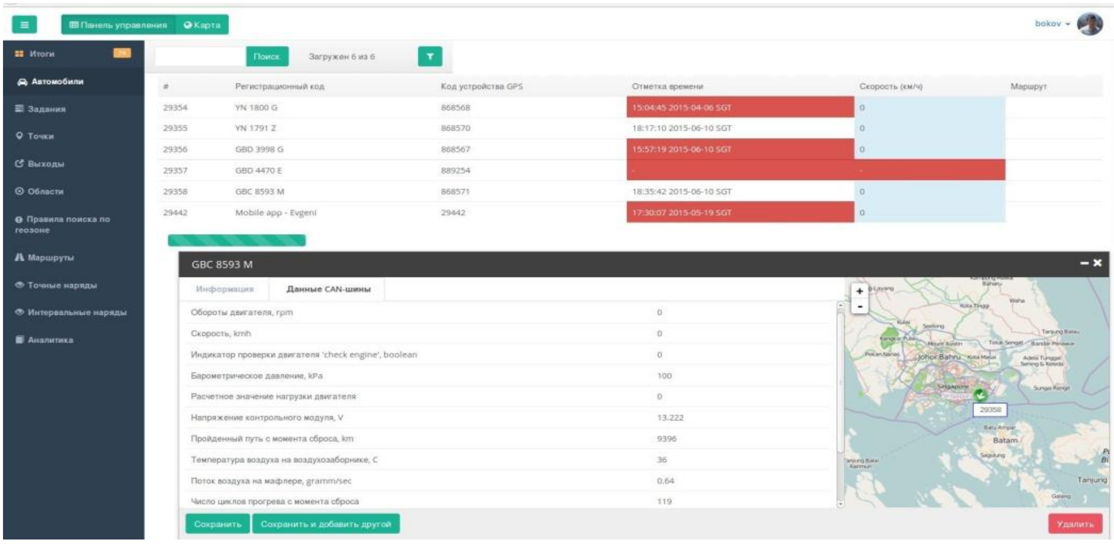

Figure 4 – A screen of the system «BaseRide»

Universal systems provide opportunities for receiving data on congestion and passenger transport. These features require the installation of special optical sensors on the vehicle to directly count the number of incoming and outgoing passengers. This method of assessing the congestion of municipal transport seems unrealistic in the conditions of passenger traffic in megacities.

All existing information systems for urban transport can also be divided into two types: for passengers and for dispatchers.

An example of passenger-oriented systems is [8, 9]. The Smart Area system [9], which is being developed as part of the «Zupinka» project and has already been launched in test mode in the city of Kharkiv (Fig. 5).

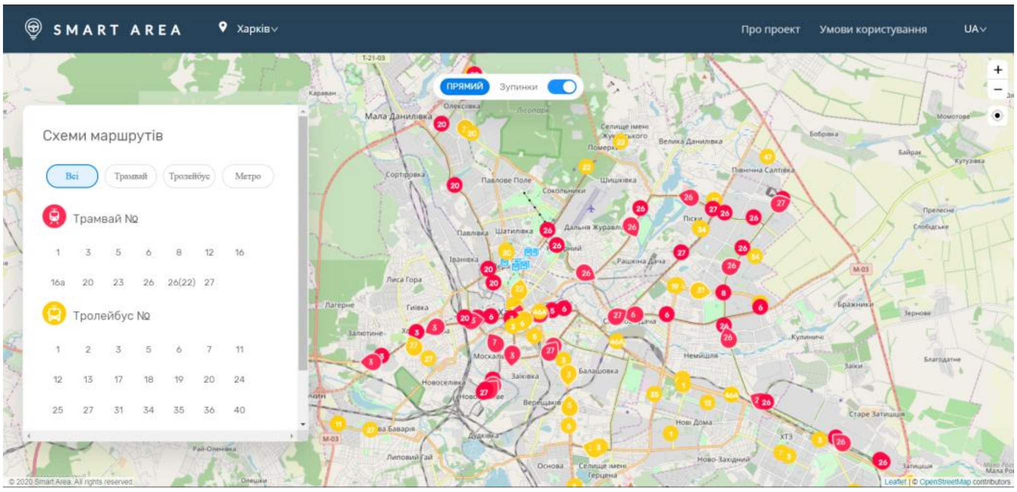

Figure 5 – Information system Smart Area in Kharkiv

This system allows residents of the metropolis using a smartphone to track the movement of trams and trolleybuses along routes. It is also possible to receive information about the arrival time of the transport to the stop and about the number of transport units on the route.

In the new version of the system, it is supposed to display information about changes in public transport routes, as well as to add the function of creating an individual route with the determination of transfer points and cost. The use of such systems as means of traffic control is not intended by developers.

An example of TMIS for dispatchers can be considered a system that is implemented by the Lviv Transport Administration [10]. The vehicles are equipped with GPS devices, and the computers of the LME «Lvivelectrotrans» dispatchers with special software. Also installed feedback tools with drivers. This makes it possible in real time to control the timetable, the number of trams and trolleybuses on the routes. Obtaining information on the congestion of a transport unit is not provided.

3. The quality of passenger service by urban electric vehicles

The quality of urban transport is determined by the quality of the economic organization of transport (the number and ramification of routes, the condition of park services, tracks and rolling stock, etc.) and the quality of the dispatch service [11].

The main task of the dispatch service is to ensure consistency between the passenger flow and the intervals of traffic between stops on the route. Currently, such compliance is established mainly using traffic schedules.

The table 1 shows the real data [12] for a largely typical for Kharkiv trolleybus route number 2.

Table 1 – Passenger traffic and trolleybus intervals for route #2 in Kharkiv city

Timeline	Passenger flow (pass/min) (Weekdays)	Interval (min) (Weekdays)	Passenger flow (pass/min) (Weekends)	Interval (min) (Weekends)
Morning	15	8	10	10
Day	10	8	17	10
After 8 p.m.	7	9	19	10

The total number of seats in the vehicle of this route is 150 passengers.

To assess the quality of the work of the dispatching service, we use the quality indicator proposed in [11] – probability P of the refuse a passenger a ride at a stop due to overloading of vehicle.

Fig. 6 and 7 show these dependencies for data in the table. In these figures, curves 1 corresponds to morning hours, curves 2 to daytime and curves 3 to evening time.

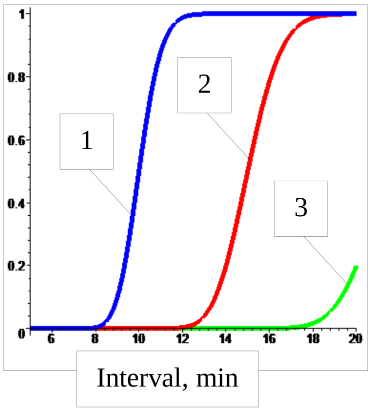

Figure 6 – Dependence of the probability of the refuse a passenger a ride on the interval of traffic on a weekday

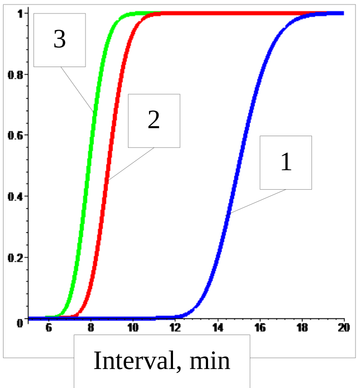

Figure 7 – Dependence of the probability of the refuse a passenger a ride on the interval of traffic on a weekend

In the daytime of the working day (curve 2 in Fig. 6), the probability of refusing a ride becomes critical $(P > 0{,}87)$ only if you are late for a time longer than the interval of movement $(i > 8\,\text{min})$.

On weekdays in the morning, the interval of movement is 8 minutes (table) and the probability of failure if the schedule is observed is small $P(8) = 0{,}003$. But $P(10) = 0{,}77$ and $P(11) = 0{,}87$. That is, at peak hours (curve 1), the probability of the refuse a ride becomes critical already with a two-minute lag of the trolleybus from the schedule.

On weekends in the morning (Fig. 7, curve 1), traffic is free and traffic irregularities are allowed over a wide range. In the daytime (curve 2), and even more so in the evening (curve 3), the probability of a denial of transportation is very high, even if the traffic schedule is observed, and is $P(10) = 0{,}93$P and $P(10) = 0{,}99$, respectively.

The above examples show how much the quality of the dispatch service depends on the correct choice of the interval of movement, i.e. the number of transport units on the route. At the same time, the determining factor for the dispatcher is the ability to estimate passenger flow values in real time.

Currently, the distribution of passenger traffic over time is determined based on heuristics or statistical studies. However, this multifactorial quantity has a hyper-random [13] and even chaotic nature [14], which is poorly modeled by existing engineering methods.

Based on the foregoing, it can be concluded that currently the dispatch services of urban transport in metropolises have sufficient means to monitor the movement of vehicles and control the actions of drivers in real time.

However, the current TMIS does not have the means for monitoring passenger flow and vehicle occupancy in real time. The accumulation of data on passenger flows is practically non-existent, which would allow the use of modern Data Mining methods to obtain data on the regularities of changes of this characteristic of a complex nature. In general, the combination of all factors, in our view, is the reason for the decline in the quality of work and, as a result, the decrease in the volume of passenger transport by land electric transport.

Thus, the development of an automated information system that would make it possible to obtain, collect and store real-time data on passenger flows and occupancy rate of urban traffic is an urgent task. Visualization of the data on the dispatcher's screen, as well as the knowledge of the regularities of their changes, will contribute to the improvement of operational decisions on the municipal ground electric transport traffic management. The work proposes a concept for such a system.

4. Determination of the congestion on electric vehicles according to the power consumed by engines

This approach seems to be the simplest in terms of technical implementation. All necessary measuring instruments and GPS sensors are standard equipment for modern rolling stock.

To describe the concept of the proposed IS in this work it is sufficient to consider straight sections of the transport route. Also to simplify matters, it is assumed that the power consumed is measured on the track where the tram is moving at a steady speed. In this case, the force of the tram is equal to the force of the rolling friction. A more complex model, which accounts the unevenness and other factors of traffic on the route, if necessary, can be based on, for example, using the model proposed in [15].

Under the assumptions made, the work of A moving the transport unit by force F along the route from some starting point M_0 to point M (Fig. 1) at a constant speed v in time t is equal to

$$A = Fvt \quad (1)$$

and the power consumed

$$N = Fv\,. \quad (2)$$

Fig. 8 shows the rolling stock M. which moves evenly up at an angle of α. In this figure, F is the force that ensures the smooth movement of the rolling stock, F_{rf} – rolling force, F_{ff} – friction force, P – weight of rolling stock, P_n – normal pressure force.

At the same time, the force values are related by the ratio

$$F = F_{rf} + F_{ff}\,, \quad (3)$$

where $F_{rf} = P\sin\alpha$, $F_{ff} = P_n k$, k – rolling friction coefficient, $P_n = P\cos\alpha$, $P = P_{urs} + P_{pass}$, P_{urs} – unladen rolling stock weight, P_{pass} – total passengers inside rolling stock.

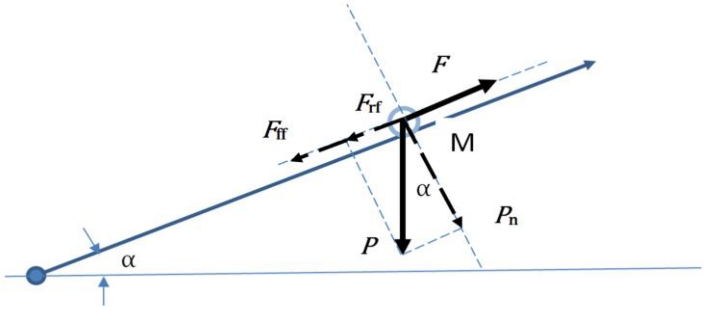

Figure 8 – Steady Hoisting of the vehicle

Setting the values to all these ratios in (3), we get

$$F = (P_{urs} + P_{pass})(k\cos\alpha + \sin\alpha), \qquad (4)$$

Setting the values from (4) to (2), we get the ratio.

$$P_{pass} = \frac{N}{v\beta} - P_{urs}, \qquad (5)$$

where $\beta = k\cos\alpha + \sin\alpha$, $k = f * R * n$, R – wheel radius, n – amount of wheels.

The value f can be estimated as follows: [16]: $f = 0,05\, cm^{-1}$ for tram and $f = 0,0524\, cm^{-1}$ for trolley.

For a route containing horizontal sections, lifts and lowers (Fig. 9), the ratio (5) does not change. Only the value of the parameter β changes, as follows:

$$\beta = \begin{cases} k & horizontal \\ k\cos\alpha + \sin\alpha & uphill \\ k\cos\alpha - \sin\alpha & downhill \end{cases}. \qquad (6)$$

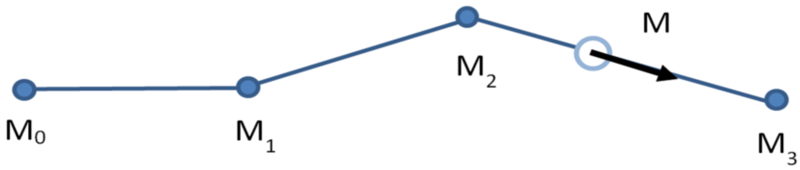

Figure 9 – Changing the relief on the route of rolling stock

The value of the power consumed by the engines is determined by the instruments of the vehicle. Using the ratios (5) and (6), it is possible to estimate the useful occupancy rate of a given section of the route. If a linguistic variable is defined for this data stream [17] with values, for example, {empty, unladen, crowded, overcrowded} and each value matches the color of the transport unit mark on the monitor, then the dispatcher receives additional important information for making better transport management decisions in the conditions of passenger flows changing.

5. TMIS Concept

The overall concept of TMIS is as follows:

• The rolling stock (trams, trolleybuses) is equipped with a set of devices (GPS sensor, wattmeter, inclinometer, speedometer), as well as equipment for digitizing and transmitting data to the server for processing.

•After the ADC (Analog to Digital Converter), the data will be transmitted to the server through the use of a mobile network (the choice is based on the high speed of the Internet as well as the full coverage within the city).

• Data processing on the server is carried out using cloud technologies, namely:

– data transfer to «cloud»;

– storage of data for further processing by Data Mining methods;

– preparation and dispatching of the data to dispatcher's monitor for traffic visualization.

• The dispatcher screen displays the routes on which each rolling stock is shown as a label whose position and color changes in real time.

• When the cursor is placed on the mark, data about compliance with the movement schedule appears nearby.

• If the rolling stock is critically off-schedule, an additional mark (such as an exclamation mark) automatically appears next to the movement mark, symbolizing the dispatcher's intervention.

• The dispatcher sees the whole situation on the routes and makes decisions based on the received data.

The following is a contextual diagram of the main functions of TMIS (Fig. 10) and a flowchart (Fig. 11) of the control of electric transport on the route using this information system.

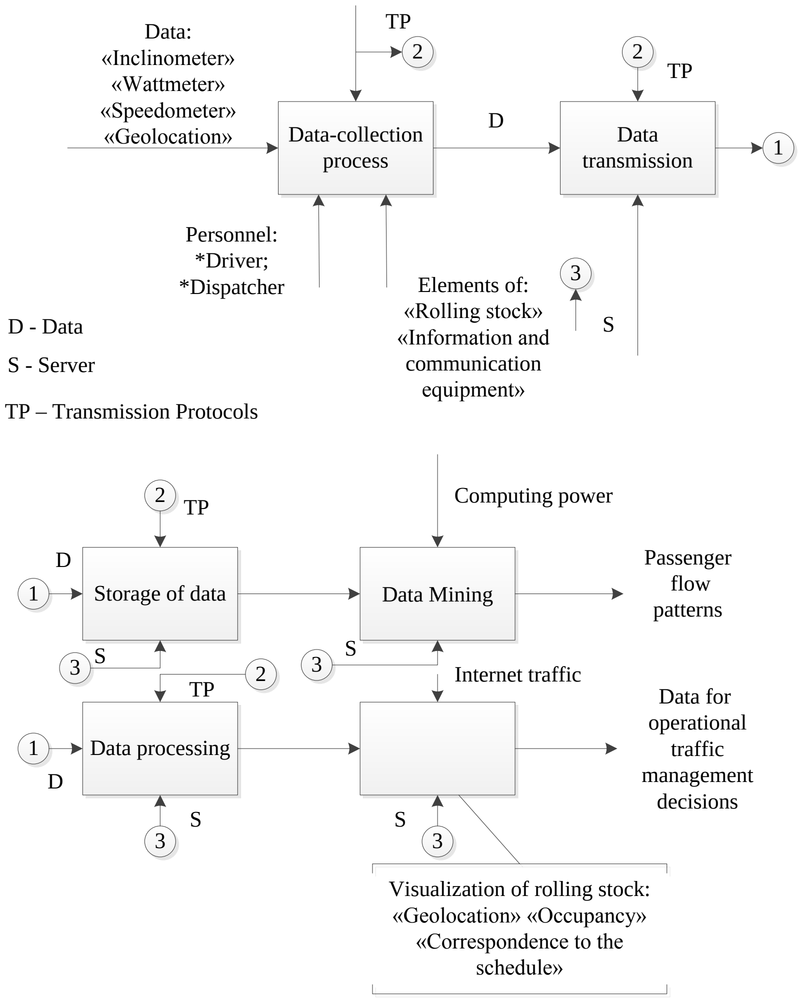

Figure 10 – Context diagram of the first level of TMIS functions

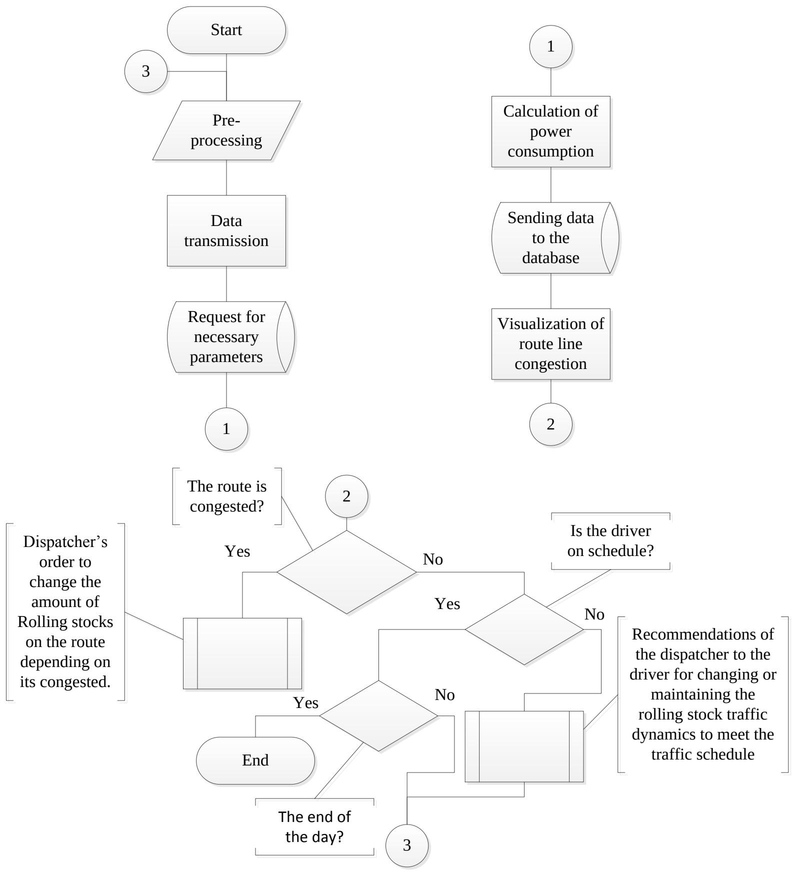

Figure 11 – Flowchart of Electric Vehicle Management using by TMIS

6. Conclusions

The article shows, with a specific example, that the quality of passenger service is so heavily depends on passenger traffic that municipal land-based electrical transport can be characterized as a system critical to the intended use.

It is proposed the concept of the system, the main difference of which from the existing systems, is that it in real time, besides geolocation, allows to inform dispatcher about the degree of occupancy rate of transport units on routes.

The system will also collect store and process data to identify hidden patterns in passenger flows.

Real-time passenger information and knowledge of the regularities of change will improve the performance of municipal surface electric transport.

REFERENCE

1. Urbanization, Population, and Health Myths: Addressing Common Misconceptions with Strategic Health Communication. Springer. URL: https://link.springer.com/chapter/10.1007/978-1-4614-9335-8_3 (last accessed: 08.05.2020).
2. Le Corbusier S. Urbanisme. Paris: Les Editions G. Crès &Cie, 1924. 301 p.
3. Tram routes. Kharkov. URL: https://tvoj.kharkov.ua/help/Tramway/ (last accessed: 01.05.2020).
4. Metro map. Kharkov. URL: https://kartametro.com.ua/karta-metro-xarkov/ (last accessed: 01.05.2020).
5. Intelli. The Best GPS Transport Monitoring Systems in Ukraine. URL: https://intelli.com.ua/ (last accessed: 16.04.2020).
6. CAPTERRA. Best Transportation Dispatch Software 2020. URL: https://www.capterra.com/ transportation-dispatch-software/m (last accessed: 18.04.2020).
7. BaseRide, CloudBus. URL: http://baseride.com/ru/cloudbus/ (last accessed: 25.03.2020).
8. ISGEO. Passenger Transportation Management. URL: http://www.isgeo.com.ua/en/solutions/carriers/

city-transport-management (last accessed: 16.04.2020).
9. SmartArea. SmartCity. URL: https://smartarea.info/ua/Kharkiv/ (last accessed: 12.04.2020).
10. KP.UA. Satellite will control the operation of trams and trolleybuses – News on KP.UA. URL: https://kp.ua/lvov/368822-rabotu-tramvaev-y-trolleibusov-budet-kontrolyrovat-sputnyk/ (last accessed: 30.11.2019).
11. Khudiakov V. Study of the evaluation of the quality of passenger services in Riga by the year 2018. *RESEARCH and TECHNOLOGY – STEP into the FUTURE*. 2007. Vol. 2, N 2. P. 5–14.
12. City Kharkov. Trolleybus Official site of Kharkov city council, mayor, executive committee. URL: https://www.city.kharkov.ua/uk/dovdnik/transport/trolejbusi.html (last accessed: 09.04.2920).
13. Gorban I.I. Theory of hyper-random mass phenomena. Kyiv: Naukova dumka, NAS in Ukraine, 2011. 184 p.
14. Gleick J. Chaos: Making a new science. New York: Viking, 1987. 475 p.
15. López J., Herrera V., Camblong H., Milo A., Gaztañaga H. Energy Management Improvement Based on Fleet Digitalization Data Exploitation for Hybrid Electric Buses. Computational Intelligence and Optimization Methods for Control Engineering. P. 321–355. URL: https://link.springer.com/chapter/10.1007/978-3-030-25446-9_14 (last accessed: 15.04.2020).
16. Tehtab.ru Coefficients of rolling friction – tables. URL: https://tehtab.ru/guide/guidephysics/frication/frictionofrolling/ (last accessed: 01.04.2020).
17. Zadeh L. The concept of the linguistic variable and its application to approximate decision-making. Moscow: Myr, 1976. 165 p.

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