The Smart Urban Transport System

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***Abstract*—In the paper principles of functioning an intelligent urban transport system based on unmanned electric vehicles which capable of adapting to passenger traffic's changes in real time are considered. The algorithm of drawing up a plan of passenger transportation by means of such transport system and cassette-conveyor method of passenger delivery are described. The upper limit of the necessary number of transport units for the implementation of the distribution plan is given.**

***Keywords*—Smart Urban Mobility, Smart Urban Transport Vehicle System, Infobus, Unmanned Vehicles**

I. Introduction

Continued urbanization and the increasing density of population and traffic flows in cities are creating the discomfort of living and using transport systems that built on the solutions of past years. At the same time, the development of information technologies and technology platforms makes it possible to address emerging social and environmental issues and to balance different types of traffic flows (pedestrian, bicycle, new-mobility, motor vehicles). One of these approaches is called Smart Urban Mobility (SUM, Smart Urban Mobility), Fig.1.

Figure 1. Example of a figure caption.

Within the paradigm SUM the concept of public transport system, developing from the point of view of priorities of passengers and pedestrians interests - PRT (Personal Rapid Transit) is received recognition. PRT - transport systems use small unmanned vehicles which moving on a dedicated line, which carry out transportation mainly in the mode of "origin - destination", i.e. movement "on demand" of the passenger from the initial stop to the final one without intermediate stops. Also distinguishing features of PRT-transport are minimization of waiting time and small volume of the cabin, which provides privacy of the trip, comparable to the conditions of private transport. At present, PRT transport systems are successfully used in the West in highly connected cluster logistics terminals: airports, railway stations, university and medical infrastructures located in different parts of the metropolis. As a concrete example, the use of PRT-transport system in Heathrow airport, England.

II. Smart urban transport passenger system

A. Description of smart transport system

The proposed article describes a PRT-like transport system designed for mass passenger transportation based on the use of unmanned electric vehicles and describes the principles of its operation. This intelligent transport system carries all the features of PRT, but can also act as an alternative to traditional public transport, offering a new method for the implementation of passenger transportation: cassette-conveyor transportation, the essence of which is a continuous (conveyor), with small intervals, sending to the route of electric cars connected to virtual couplings in cassettes, consisting of the necessary number of vehicles, as in road trains [1]. The passenger capacity of such cassettes provides with a small excess of the volume of requests for service from the passenger trains. The cassette picks up all passengers travelling to several neighboring stops on the route, thus combining public transportation and PRT: the cassette can carry quite a large number of passengers, comparable to transport with increased passenger capacity, and at the same time, passengers travel with a minimum number of stops during the journey. Thus, the proposed intelligent transport system consists of:

- a fleet of small-capacity unmanned electric cars, called infobuses, which are remotely controlled by a single information center (server) and are sent to the route depending on the intensity of passenger traffic so as to slightly overlap it, Fig. 2a;
- a system of terminals for payment and collection of requests for delivery from passengers that are placed at the route stops, as shown in Fig. 2b;
- a two-way route consisting of k stops, as shown in Fig. 3;

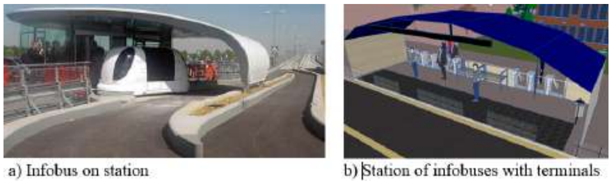

Figure 2. Infuses and its stations

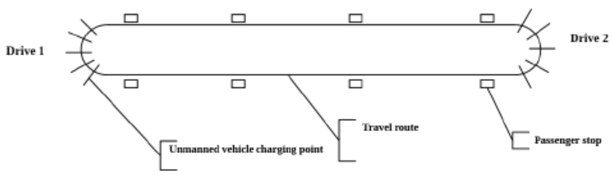

Figure 3. The Route of infuses

B. Functioning of smart transport system

Infobuses move along a dedicated line on the carriageway one after the other without overtaking, which is risky road maneuver, thus significantly improving the safety of the journey, if necessary, united by virtual connections into cassettes. When paying at a stop through the terminal, the passenger also indicates the stop to which he wishes to go. Requests from stop points are received by the information transport system server and it forms a special correspondence matrix M_z, *Z=1,2, ...*, recording each arriving passenger at the stop. Each element m_{ij} of matrix determines the number of passengers going from stop *i* to stop *j*, $i = \overline{1, k-1}, j = \overline{2, k}$,where *k* - the number of stops in one direction of the route.

$$M_z = \begin{pmatrix} 0 & m_{1,2} & \cdots & m_{1,k-1} & m_{1,k} \\ 0 & 0 & \cdots & m_{2,k-1} & m_{2,k} \\ \vdots & \vdots & \ddots & \vdots & \\ 0 & 0 & \cdots & 0 & m_{k-1,k} \\ 0 & 0 & \cdots & 0 & 0 \end{pmatrix} \quad (1)$$

The matrix of correspondence is fixed and the server begins to form the delivery plan of passengers on it , when one of its elements will satisfy a condition:

$$m_{ij} = a * V, a \in [0.5, 1), i = \overline{1, k-1}, j = \overline{2, k} \quad (2)$$

where a is the *elasticity coefficient* that provides places for passengers, who will arrive to a stop between the moment of beginning of drawing up of plan and the moment of arrival of an infobus on stop, V - volume of an infobus.

Thus, of drawing up a distribution plan, it is determined:

- the number of infobuses involved
- a serial number $n_i \in N$ for each used infobus, where *i* - indicates the initial stop from which the infobus will take the passengers
- a set of delivery stops for all infobuses of a delivery plan $\bigcup_{i=1}^{k-1} \bigcup J_{n_i}$, where the content of the set J_{n_i} indicates the sequential numbers of stops on which passengers will leave the infobus.

During the drawing up the delivery plan each string *i* of M_z , which contains information about the requests of passengers travelling from stop *i* to next stops of route, is processed. For insurance non - conflict motion of infobuses during transportation of passengers from origin stop *i*, the infobuses will be sent first to distant stops, then to the nearest: $j = k, k-1, ..., i+1$. Thus, each infobus receives its own sequential number n_i. That means, the first infobus receives a number 1_1,when it will transport passengers from the first stop (when processing the first line of M_z matrix) . It will deliver passengers to the last stop *k* and, possibly, to some neighboring stops $k-1, k-2, ...$. The total number of passengers , which travel to these stops, can not exceed the *V* volume of the infobus.

Each infobus with an sequential number n_i has its own set of available stops. In the algorithm it will be called a *potential set of stops* and will be marked J_{n_iP} . It includes all stops on the route behind the original infobus stop, except for those stops to which previous infobuses from the same stop have already delivered passengers. Such infobus will deliver the passengers to stopping points that constitute a *real set of stops* J_{n_i} , and which is a subset of a *potential set of stops* $J_{n_i} \in J_{n_iP}$.

The exact upper boundary (the smallest upper boundary) of numerical set *M* in mathematics is called *supreme* and is signed *sup M* [2].

The stop with the greatest ordinal number of a *potential set of stops* J_{n_iP} of an infobus n_i will be an exact upper boundary of set J_{n_iP} and is signed as $supJ_{n_iP}$ (supreme J_{n_iP}), and always will enter into *real set of stops* J_{n_i} of an infobus n_i. Whether this set will include other stops depends on the volume of the infobus and the number of passengers coming to them.

To determine the *real set of stops* J_{n_i} of the infobus n_i , the algorithm uses a value δ_{n_i} that represents the number of stops that entered the *real set of stops* J_{n_i} of the infobus without stopping $supJ_{n_iP}$, or $\delta_{n_i} = |J_{n_i}| - 1$. Thus, for an infobus n_i , the *potential set of stops* J_{n_iP}, the value δ_{n_i} and the *real set of stops* J_{n_i} are determined from the following conditions [3-12]:

$$
\begin{cases}
J_{n_i P} = \{i+1, ..., k\} \setminus \bigcup J_{n_i - 1}, \\
J_0 = \emptyset \, n_i, \delta_{n_i} \in N_0, \\
\sum_{j=SupJ_{n_i P} - \delta_{n_i}}^{SupJ_{n_i P}} m_{ij} \leq V, \\
\sum_{j=SupJ_{n_i P} - \delta_{n_i} - 1}^{SupJ_{n_i P}} m_{ij} > V \\
J_{n_i} = \{j | j \in N_0, \\
SupJ_{n_i P} - \delta_{n_i} \leq j \leq SupJ_{n_i P}\}
\end{cases} \quad (3)
$$

Also, the proposed smart transport system is able to determine stopping points from real set of stops delivery J_{n_i} of infobus n_i, where vehicle can after disembarking also pick up additional passengers who are going to go to his next stops of the set delivery J_{n_i} . In another words, all passengers (who going to the next stopping points of real stop set J_{n_i}) are taken in the vehicle from the disembarking stop of set J_{n_i}, if their total number does not exceed the current amount of available seats in the infobus.

As an example, let's consider the fourth line of some correspondence matrix 10×10 :

$$
\begin{pmatrix} 0 & 0 & 0 & 0 & 2 & 4 & 6 & 3 & 7 & 15 \end{pmatrix}
$$

Let at this stop after disembarking of passengers the amount of available seats in some infobus with the number $n_i, i < 4$ is equal to 11, and real set of delivery stations is $J_{n_i} = \{4, 5, 6, 7, 8, 9\}$. In this case passengers are travelling from the fourth stop to the stops {5,6,8} can enter the infobus: $2 + 4 + 3 < 11$, or to {6,7} : 4+6<11, or {6,9}: 4+7=11 and so on. In another words, the set of such stops is variable and determines the number of infobuses that are involved in the transportation plan and the volume of used passenger capacity of the vehicle's cabin .

With the help of the developed software for drawing up delivery plan the simulation of the model's work was carried out using three algorithms of forming such sets stopping points: sequential selection of stops, greedy algorithm and dynamic method of the task of filling the knapsack , using such indicators as the *number of infobuses involved* and *coefficient of use passenger capacity of vehicle* K_{pc}, which is determined by the formula:

$$
K_{pc} = \frac{\sum_{i=1}^{n_{span}} (1 - V_{fp_i})}{V \times n_{span}} \quad (4)
$$

where V - infobus passenger capacity, n_{span} - the total number of all spans (intervals between neighbouring stops) on which the infobuses of delivery plan carried passengers, V_{fp_i} - is the amount of free places in the infobus on the span.

On the basis of 1000 tests data, that represent the dependence of the average *number of infobuses involved* and the average value of *the coefficient of use of passenger capacity* K_{pc} as a function of the value of the *elasticity coefficient* ***a*** on the above three algorithms of choice of stops for additional boarding of passengers, are shown in Fig. 4 and Fig.5 .

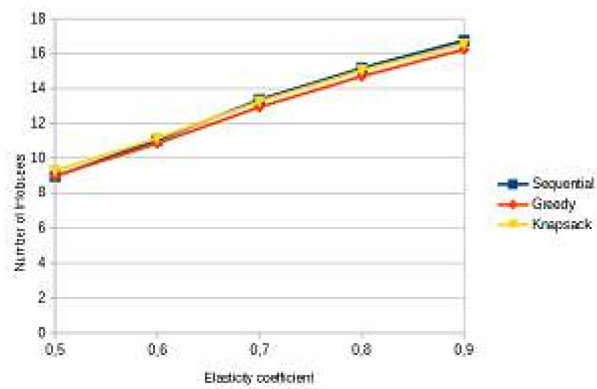

Figure 4. Dependence of the average infobus number on the elasticity coefficient.

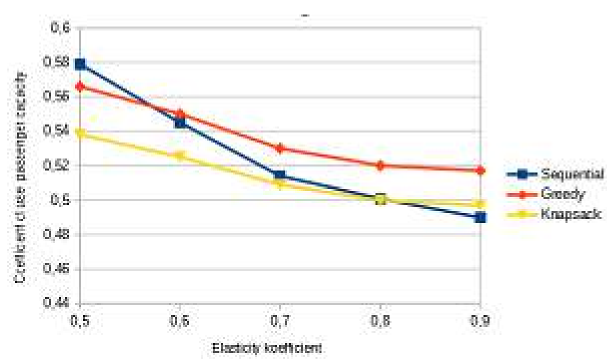

Figure 5. Dependence of the average coefficient of use passenger capacity on the elasticity coefficient.

These tests have demonstrated the greatest effectiveness of the greedy method of selecting additional boarding stops over the entire determination area.

C. Estimation of the upper limit the number of infobuses used

The upper limit of the required number of infobuses can be estimated with an odd number of stops as well as $N_{ul} = \frac{k^2-1}{4}$, with an even number of stops $N_{ul} = \frac{k^2}{4}$. The correctness of calculation of the upper limit has been confirmed experimentally. Fig. 6 shows a graphic of the dependence the number of used infobuses on the number of stops $k = 7$ ($N_{ul} = 12$) in one direction of the route for three value of elasticity coefficient .

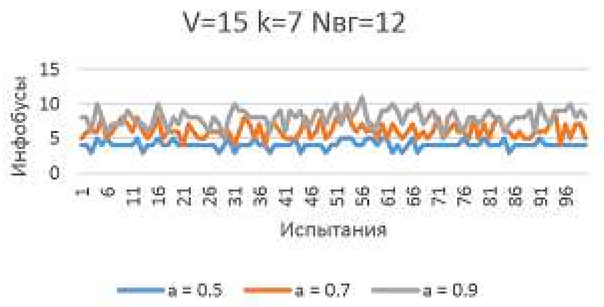

Figure 6. Dependence of the number of used infobus on the number of stations.

CONCLUSIONS

The paper describes the principles of functioning a smart urban passenger transport system based on the use of remotely operated by server unmanned vehicles called infobuses, which could become a new type of public transport. This type of transport is capable of operating without interference from other vehicles in a busy street and road environment and carrying a number of passengers comparable to the subway, with not only economic but also environmental benefits. And also the algorithm of drawing up of the plan of transportation of passengers by means of the given transport system with use of a conveyor-cassette mode of transportation which allows functioning it independently without participation or with the minimum participation of the person is described. The work is relevant, as the proposed transport system is able to show adaptability to the dynamics of changes in road and transport conditions.

REFERENCES

[1] SARTRE.Available at: http://en.wikipedia.org/wiki/Safe Road Trains for the Environment (accessed:09.01.2020).

[2] Rudin, W. 1976. Chapter 1. The Real and Complex Number Systems. Principles of Mathematical Analysis. McGraw-Hill:p.4

[3] A.N. Zhogal, V.N. Shut', E.V. Shvetsova. Avtomaticheskii gorodskoi intellektual'nyi passazhirskii transport[Automatic urban intelligent passenger transport].Transport i innovatsii: vyzovy budushchego: materialy Mezhdunarodnoi nauchnoi konferentsii [Transport and innovation: challenges for the future: proceedings of the International Scientific Conference],2019, Minsk: Natsional'naya biblioteka Belarusi,pp.23-33

[4] E.V. Shvetsova, V.N. Shut'. Algoritm sostavleniya plana perevozok na gorodskikh liniyakh v intellektual'noi sisteme upravleniya bespilotnymi transportnymi sredstvami[Algorithm of drawing up a plan of transportation on urban lines in the intellectual system of management of unmanned vehicles].Vestnik Khersonskogo natsional'nogo tekhnicheskogo universiteta[Herald of Kherson National Technical University],2019,vol.2(69),no3,pp.222-230

[5] E.V. Shvetsova, V.N. Shut'. Algoritm sostavleniya plana perevozok na gorodskikh liniyakh v intellektual'noi sisteme upravleniya bespilotnymi transportnymi sredstvami [Algorithm of drawing up a plan of transportation on urban lines in the intellectual system of management of unmanned vehicles]. Materialy XX mezhdunarodnoi konferentsii po matematicheskomu modelirovaniyu: sbornik materialov konferentsii [Proceedings of the XX International Conference on Mathematical Modelling: a collection of conference proceedings],2019, p.115

[6] V. Shuts, A. Shviatsova. System of urban unmanned passenger vehicle transport. ICCPT 2019: Current Problems of Transport: Proceedings of the 1st International Scientific Conference, 2019,pp. 172-184

[7] V.N. Shut', E.V. Shvetsova. Algoritm organizatsii gorodskikh passazhirskikh perevozok posredstvom rel'sovogo bespilotnogo transporta "Infobus"[Algorithm of organization of city passenger transportation by means of rail unmanned transport "Infobus"].ACTUAL PROBLEMS OF FUNDAMENTAL SCIENCE: third international conference,2019,pp.222-226

[8] V. Shuts, A. Shviatsova. Cassette robotized urban transport system of mass conveying passenger based on the unmanned electric cars. Science. Innovation. Production. Proceedings of the 6th Belarus-Korea Science and Technology Forum, 2019,pp.81-83

[9] V. Shuts, A. Shviatsova. Intelligent system of urban unmanned passenger vehicle transport. Abstracts of the 16th European Automotive Congress (EAEC 2019) hosted jointly the Academic Automotive Association (Belarus), the European Automobile Engineers Cooperation (EAEC) and the Federation Internationale des Societes d'Ingenieurs des Techniques de l'Automobile (FISITA),2019,pp.18

[10] E.V.Shvetsova, V.N.Shut'. Bezopasnost' bespilotnykh transportnykh sistem[Safety of Unmanned Transport Systems]. Materialy IX mezhdunarodnoi nauchno-prakticheskoi konferentsii:V 2-kh ch [Materials of IX International Scientific and Practical Conference: In 2 parts],2019,v.1,pp.90-91

[11] V.N. Shut', E.E. Prolisko, E.V. Shvetsova. Avtomatizirovannaya sistema upravleniya razdelyayushchimsya passazhirskim transportom[Automated management system for split passenger transport]. Doklady XVIII Mezhdunarodnoi konferentsii «Razvitie informatizatsii i gosudarstvennoi sistemy nauchno-tekhnicheskoi informatsii»[Reports of the XVIII International Conference "Development of Informatization and State System of Scientific and Technical Information"],2019,pp.176-180

[12] A.A. Burov, D.O. Boiko, E.V. Shvetsova. Algoritmy funktsionirovaniya bespilotnykh gorodskikh passazhirskikh transportnykh sistem[Unmanned urban passenger transport systems operation algorithms]. Sbornik konkursnykh nauchnykh rabot studentov i magistrantov[Collection of competitive scientific works of students and master students],2019,pp.62-65

Умная городская транспортная система

Швецова Е.В., Шуть В.Н.

Данная статья посвящена описанию интеллектуальной городской транспортной пассажирской системы на основе беспилотных электрокаров, называемых инфобусами, и принципам ее фукнционирования, а именно конвейерно-кассетному способу развозки пассажиров. Во введении приведены предпосылки возникновения новых видов транспортных систем в городах и в частности PRT-транспорта. Второй раздел посвящен описанию самой транспортной системы на основе беспилотных электрокаров и алгоритмам составления плана развозки пассажиров посредством конвейерно-кассетного способа. В третьем разделе приведена оценка верхней границы использованных в плане развозки инфобусов.

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