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THE SMART URBAN TRANSPORT SYSTEM BASED ON ROBOTIC VECHICLES

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ІНТЕЛЕКТУАЛЬНА МІСЬКА ТРАНСПОРТНА СИСТЕМА, ЯКА БАЗУЄТЬСЯ НА РОБОТИЗОВАНИХ АВТОМОБІЛЯХ

This article is devoted to the description of an intelligent urban transport passenger system based on unmanned electric vehicles called infobuses, and the principles of its functioning, namely, a conveyor-cassette method of transporting passengers. The introduction describes the prerequisites for the emergence of new types of transport systems in cities and in particular PRT transport.

Keywords: passenger transport, intelligent transport, smart transport, information transport system, transport with divided parts

Дана стаття присвячена опису інтелектуальної міської транспортної пасажирської системи на основі безпілотних електрокарів, так званих ІНФОБУС, і принципам її фукнціонування, а саме конвеєрно-касетного способу розвезення пасажирів. У вступі наведено передумови виникнення нових видів транспортних систем у містах та зокрема PRT-транспорту.

Ключові слова: пасажирський транспорт, інтелектуальний транспорт, розумний транспорт, інформаційна транспортна система, транспорт з розділеними частинами

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), Pic. 1.

Pic.1. Smart Urban Mobility

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 air-port, England.

Formulation of the problem

Traditional private transport is not able to provide a high transport capacity because according to information [1] in each car moves on average 1.2 -1.5 human. Hence, for avoiding traffic conflicts it is need to unload oversaturated roadways through the expansion of public land transport with high performance comparable to subway.

In the practice of transportation for describing of the needs urban passengers and for regular analyze the conditions of passenger transportation a category is named "passenger traffic" [2,3] is used, that is characterized by "intensity" (average number of passengers that are transported per unit of time). Data about the intensity of passenger traffic are used for choice the type of transport with necessary capacity and determine the number of vehicles are required for transportation.

The vehicles of different capacity can be used on each route. The choice and justification of the required vehicle capacity for quality passenger service is a complex managerial task, especially in the conditions of incomplete and often not reliable information. The capacity of the vehicle is determined according to the distribution of the intensity of passenger traffic and the pattern of its unevenness in time along the route and directions. Often the information is probabilistic.

Thus, the current state of passenger traffic has the following disadvantages:

- the absence of objective information in real time about the intensity of passenger traffic on the route that prevents the adoption of optimal decisions and leads to economic losses;
- the presence of the human factor in making responsible decisions on the choice of the quantity and volume of the vehicles that must be sent to this route and at this time of day;
- the small nomenclature of vehicles of different capacity to more accurately cover the changing passenger traffic. Unfortunately, this drawback in modern technical support of urban passenger transport vehicles is impossible to overcome, since the industry is not able to manufacture many types of buses of different capacity.

The proposed article describes a smart urban 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 private, but can also act as an alternative to traditional public transport that offers a new method for the implementation of passenger transportation: cassette-conveyor transportation.

Main achievements analysis

The last decade is characterized by active development in the field of autonomous and unmanned vehicles. Many scientific works, studies, publications and books are dedicated wide coverage of aspects road unmanned vehicle automation, including management, social consequences, legal issues and technological innovations from the perspective of many public and private actors. In those works the current situation and prospects for the development of unmanned vehicles, traffic planning, traffic safety with the participation of unmanned vehicles are analyzed. (Meyer & Beiker, Road vehicle automation, 2014) [4], (Choromanski, Grabarek, Kowara, & Kaminski, "Personal Rapid Transit—Computer Simulation Results and General Design Principles", 2013) [5], (Chen & Li, Advances in intelligent vehicles, 2014) [6], (Bucsky, "Autonomous vehicles and freight traffic: towards better efficiency of road, rail or urban logistics?", 2018) [7], (Wagner, "Traffic Control and Traffic Management in a Transportation System with Autonomous Vehicles", 2016) [8], (Friedrich, "The Effect of Autonomous Vehicles on Traffic", 2016) [9].

The urban public transport will include the possibilities and features of personal transport (Anderson, Contributions to the Development of Personal Rapid Transit, 2016) [10]. Personal Rapid Transit (PRT) is a transport system that meets the following seven criteria set by The Advanced Transit Association (ATRA): fully automatic vehicles (without drivers); vehicles are only on special paths (guideway), which are intended for the exclusive use of such vehicles; small vehicles are available for exclusive use by one passenger or a small group that travels together in their choice - without random travel companions. Transport services are available 24 hours a day; small special paths may be above ground, at ground level or underground; vehicles can use all special paths and stations in a single PRT network; direct communication from the point of departure to the point of destination, without the need to transfer or stop at intermediate stations; transportation services are available on demand, not on fixed schedule (Personal rapid transit. (2019, March 02). Retrieved April 27, 2019, from https://en.wikipedia.org/wiki/Personal_rapid_transit) [11], (Baumgartner & Chu, "Personal Rapid Transit User Interface", 2013) [12], Mcdonald, S. S. (2013). Personal Rapid Transit and Its Development. Transportation Technologies for Sustainability, 831-850) [13].

Purpose of the study

The purpose of this work is a describing of functioning smart urban transport system that is located between personal and public transport in terms of consumer qualities. The system is very close to personal automatic transport, but differs from it by high carrying capacity as opposed to PRT. The paper describes a new kind of urban mobility: conveyor-cassette urban passenger transport. Also in paper algorithms of drawing up of passenger delivery plan by using of that transport system is described.

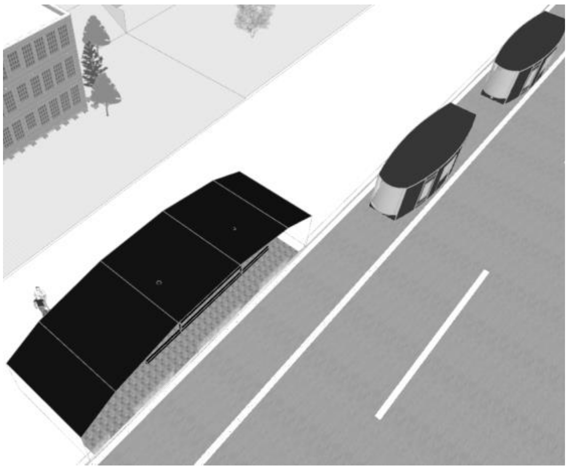
Conveyor & cassette method of urban passenger traffic

The evolution of information technology allows to revise the structure and concept of management of modern urban transport. In particular, the entire diversity of urban passenger vehicles can be reduced to one transport unit of nominal capacity that is named "infobus". Infobus is an unmanned electric vehicle with a small capacity (up to thirty passengers). Depending on the intensity of the passenger traffic on the route (measured by sensors in automatic mode) the control computer (coordinating server) sends such a number of infobuses to the route so that their total volume was equal to or slightly higher than the passenger traffic. In this case the infobuses are collected in cassettes (it determines the term “cassette type of transport”) which can consist of various quantity of units of infobuses (one, two,...) depends on the passenger traffic at the current time. This approach gives possible quickly and inexpensively to assemble a vehicle of any capacity that is required on the route now, since there are no mechanical connections in the cassette. All connections in the cassette of infobuses is virtual as in the road trains [14]. The minimum safe distance between the infobuses in cassette of infobuses is controlled electronically.

When the passenger pass through the turnstile and payees the fare, he indicates the destination stop to which he should fare. Also in this way he initializes his appearance in the transportation system for receiving transporting using infobus train without stop or with minimum number of stopping points.

Such a transport system is adaptive to passenger traffic, because it changes oneself operational and timely and successful adapts to the current conditions. In this reason, the system is the most cost-effective and most satisfactory, because vehicles will not run half-empty or overly crowded.

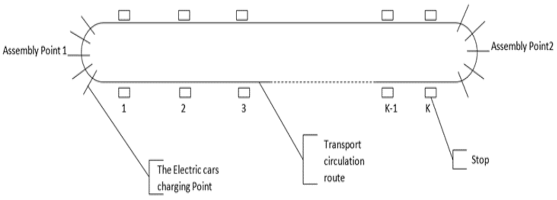
The road lane for the information buses directly adjoins the sidewalk and is separated from it by a fence and from the main road to the left by a solid line (Pic. 2).



Pic. 2. Autotrain near the station

In some cases, lightweight fencing may be used in the form of plastic cones are mounted on a solid line. The intensity of the use of road infrastructure, and in particular of road lanes, by infobuses is high. That means, the intensity of the use of road infrastructure by infobuses is higher than it is in the case of the classic road lane, since the transportation of an equal number of passengers by a narrower vehicle requires a greater number of vehicles, therefore, the road lane for them will be constantly involved.

Another important point in the definition of this transport system is such its property as conveyor. That means, as in any conveyor, the movement of infobuses in such system goes along a narrow dedicated lane without overtaking. In another words any previous infobus will be always the previous, and the next one will be the subsequent always and the sequence numbering of the infobuses remains constant. The movement of infobuses is carried out from Drive 1 to Drive 2, located at the end points of the route (Pic. 3).



Pic. 3. Driving infobus route

System operation description

System of urban unmanned passenger vehicle transport consist of [15 - 19]:

- a dedicated narrow section of the roadway that adjacent to the sidewalk and fenced off on both sides, both from the carriageway and the pedestrian part;
- stopping points for boarding and disembarking passengers, equipped with turnstiles;
- fleet of unmanned vehicles (infobus), fixed small capacity (up to 30 passengers), connected with the coordinating server, whose teams are trained by the vehicle.

The functioning of the system is as follows:

- the client (passenger) at the stopping point at the time of payment through the turnstile indicates the stop to which this passenger wishes to go;
- information from the terminals goes to the coordinating server, which forms a special matrix is named matrix of correspondences M_z, $Z=1,2,\ldots,$ and contains information about points of departure and destination of passenger;
- the plan of passenger transportation begins to form after some time when information about some number of passengers has be accumulated in the matrix of correspondences M_z, $Z=1,2,\ldots$. According this information infobuses will sent to transport passengers to the destination stations;
- the intervals of movement between stops and the time of parking at stops for this system are known.

The transportation plan - is a procedure of assignment number for each infobus that will be sanded to rout line and sequential sending of numbered infobuses from Assembly Points to the route line (Pic. 3) with indicating the final destination station and, perhaps, several intermediate stopping points for each numbered infobus individually.

Each arriving infobus on departure station has information on own display about destination points also this information is shown on monitor of departure station. Passengers, which have as the final destination the proposed set of stops, take places in this infobus. The other passengers wait for their infobus.

Thus, each infobus, which has gone from the Assembly Point on the route, has an individual sequence number and a list of stations at which it needs to make a stop for unloading and loading passengers. The current matrix of correspondences M_z, $Z=1,2,\ldots$. (1)- is a base for the development of the transportation plan. When a delivery plan is developing for the current matrix of correspondences Mz, $Z = 1,2, \ldots$, it is necessary to ensure conflict-free traffic on the route.

Each element m_{ij} of the matrix of correspondences M_z, $Z = 1,2, \ldots$ determines the number of passengers which want travel from stop i to stop j $(i, j = 1, \ldots, k)$. Here k is the number of stops of one direction of the route (Pic. 3). All elements on the main diagonal of the matrix M_z and under the main diagonal are equal to zero, because that the passenger cannot get off at the stopping point, where he has sat down, and cannot drive back [15,18,19]:

$$M_z = \begin{pmatrix} 0 & m_{12} & m_{13} & \dots & \dots & m_{1j} & \dots & m_{1k} \\ 0 & 0 & m_{23} & \dots & \dots & m_{2j} & \dots & m_{2k} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & 0 & m_{ii+1} & \dots & m_{ij} & \dots & m_{ik} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & \dots & \dots & \dots & 0 & m_{k-1k} \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0 \end{pmatrix} \qquad (1)$$

A delivery plan is composed for the matrix M_Z, $Z = 1,2, ...,$ that has each element is less than the volume of the infobus V:

$$m_{ij} < V, i = \overline{1,k-1}, j = \overline{1,k}. \qquad (2)$$

The process of functioning of the transport system is cyclical and consists of repeated procedures:

- accumulation of information in the current matrix of correspondences M_Z about the passengers arriving at the stopping points;
- determination of the moment sufficient filling the current matrix of correspondences M_Z, $Z = 1,2$ ...;
- development of a delivery plan for current matrix and the implementation of this plan.

It is also assumed, that the delivery plan remains unchanged until own end regardless of the fact of arrive new passengers on stopping points during the period of its execution. Their delivery should also be provided by the current plan of delivery.

In order to ensure this, the elasticity coefficient $a \in (0.8,1)$ is introduced. Then condition (2) of the requirement for the elements of the current matrix M_Z is written as follows:

$$m_{ij} = a * V, a \in [0.5,1), i = \overline{1,k-1}, \overline{j = 1,k}. \qquad (3)$$

The start of development of the delivery plan is coming in the moment, when one of the elements of the M_Z matrix begins to satisfy condition (3) and, therefore, all elements of the M_Z matrix are less than the infobus capacity V. Moreover, must be a supply that allows transporting passengers, who has come to the station in the moment of arrive of infobus there and was not counted when the matrix M_Z has formed.

The delivery plan must be developed for each row i of the matrix M_Z in this algorithm, i.e. for passengers starting their way from stop i to the next stops.

For the ensuring the conflict-free traffic of infobuses during delivery passengers from the stopping i to further stoppings infobuses will be sent first to the most distant destination stoppings, then to stoppings that are located nearer. Each infobus receives its own sequence number varying from 1 to n_i. Here n_i is the number of infobuses are required for delivery all passengers from stopping i to all another stoppings on route, in another words to stoppings $i + 1, i + 2, ..., k$.

In more detail, this can be represented as follows: during the transporting of passengers from the first stopping (during processing the first row of the matrix of correspondences M_Z) the first infobus receives number 1. This infobus will follow to the last stopping and possibly to some neighboring stoppings provided the total number of passengers that have these stoppings as destination will not exceed the volume of the V infobus.

Each infobus with a sequence number $\dot{n}_i \in \{1, 2, ..., n_i\}$ has its own set of stoppings are available to it. For further reasoning, this set of stoppings will be called as a potential set of stoppings and indicated as $J_{\dot{n}_i P}$. This set includes all the stopping points that are located behind the starting point of departure with the exception of those stoppings, to which the previous infobuses, carrying from the same stopping, have already delivered passengers. However, the infobus will deliver passengers not to all points of the potential set of stoppings, but only to some of them. These delivery points form the set will named for further discussions as real set of stoppings of the infobus, and will be denoted as $J_{\dot{n}_i}$. It should be noted to, the real set of infobus stoppings is a subset of potential set of infobus stoppings $J_{\dot{n}_i} \subset J_{\dot{n}_i P}$.

For example, if infobus 1 goes from the first stopping only to the last two stoppings: k and k-1 (Pic. 3), then the potential set of stoppings J_{1P} of the infobus 1 will consist of all points of the route, starting from the second stopping, i.e. $J_{1P}=\{2,3,...,k\}$, and the real set of stoppings J_1 of the infobus 1 is limited to two points $J_1=\{k-1,k\}, J_1\subset J_{1P}$. If the infobus 2 following infobus 1 will came from the first stopping to the stoppings *k-2, k-3* and *k-4*, then the potential set of its stoppings is defined as $J_{2P}=\{2,3,...,k\}\setminus J_1=\{2,3,...,k-2\}$ and the real set of infobus 2 will consist of $J_2=\{k-4,k-3,k-2\}, J_2\subset J_{2P}$.

Thus, the potential set of stoppings of any infobus that make delivery from a stopping *i* is the difference of the set of all stoppings on the route, starting from stopping *i+1*, and of the set that is aggregate of stops to which the previous infobuses made a delivery.

The real set of stoppings of infobus 1 is determined from the conditions:

$$\begin{cases} m_{1k}+m_{1k-1}\le V \\ m_{1k}+m_{1k-1}+m_{1k-2}>V \end{cases} \Leftrightarrow \begin{cases} \sum\limits_{j=k-1}^{k} m_{1j}\le V \\ \sum\limits_{j=k-2}^{k} m_{1j}>V \end{cases}. \tag{4}$$

That is, the number of passengers traveling from stop 1 to the two last stoppings is less than or equal to the infobus capacity *V*, but the number of passengers traveling to the three last stops is greater than infobus capacity *V*.

According mathematical definition [20]: "The supremum (abbreviated sup; plural suprema) of a subset *S* of a partially ordered set *T* is the least element in *T* that is greater than or equal to all elements of *S*, if such an element exists." The supremum of the number set *S* is denoted as *sup S*. For further considerations, the stopping with the greatest sequence number from the potential set of infobus stoppings $\dot{n}_i\in N$ will be denoted as $\sup J_{\dot{n}_iP}$. The composition of the real set of infobus stoppings depends on its capacity and the number of passengers, but the stop with sequence number $\sup J_{\dot{n}_iP}$ will always be in the real set of infobus $\dot{n}_i$ stoppings: $\sup J_{\dot{n}_iP}\in J_{\dot{n}_i}$.

To determine the real set of stoppings $J_{\dot{n}_i}$ of infobus $\dot{n}_i\in N$, the algorithm uses a value $\Delta_{\dot{n}_i}$, that represents the number of stoppings are included in the real set stoppings of infobus $\dot{n}_i\in N$, without the stopping $\sup J_{\dot{n}_iP}$, i.e. $\Delta_{\dot{n}_i}=|J_{\dot{n}_i}|-1$. So, for infobus 1 from the example $\Delta_1=|2|-1=1$, and for infobus 2 $\Delta_2=|3|-1=2$.

For infobus 1, the conditions for determine a potential set of infobus stoppings J_{1P}, also value Δ_1, and the real set of infobus stoppings J_1 can be defined as:

$$\begin{cases} J_{1P}=\{2,3,...,k\} \\ \sum\limits_{j=\sup J_{1P}-\Delta_1}^{\sup J_{1P}} m_{1j}\le V,\ \sum\limits_{j=\sup J_{1P}-\Delta_1-1}^{\sup J_{1P}} m_{1j}>V. \\ J_1=\{j\,|\sup J_{1P}-\Delta_1\le j\le \sup J_{1P}\} \end{cases} \tag{5}$$

$$\begin{cases} J_{1P}=\{2,3,...,k\} \\ \sum\limits_{j=K-1}^{K} m_{1j}\le V,\ \sum\limits_{j=K-1-1}^{K} m_{1j}>V. \\ J_1=\{j\,|K-1\le j\le K\} \end{cases} \tag{6}$$

That is means, the real set of infobus 1 stoppings is all stoppings, starting from the last point of the route (stopping k), and in the direction of decreasing stoppings sequence numbers until the total quantity of passengers, that travel to these stops, is less than or equal to the infobus capacity. From conditions (5), (6), it follows that $J_1=\{k-1,k\}$.

The real set of stoppings J_2 for infobus 2 can be defined similarly. Infobus 2 can proceed to all other stoppings of the route that are not included in the real set of infobus 1 stoppings. Consequently, there are a potential set of infobus 2 stoppings is $J_{2P}=\{2,3,...,k\}\setminus J_1=\{2,3,...,k-2\}$. Hence, $\sup J_{2P}=k-2$. At the same time the require condition for formation of the real set of destination points for infobus 2 is: the number of passengers that travel using infobus 2 cannot exceed the capacity of the infobus 2. This requirement is described by the following system:

$$\begin{cases} m_{1k-2}+m_{1k-3}+m_{1k-4}\le V \\ m_{1k-2}+m_{1k-3}+m_{1k-4}+m_{1k-5}>V \end{cases} \Leftrightarrow$$

$$\Leftrightarrow \begin{cases} \sum\limits_{j=k-4}^{k-2} m_{1j}\le V \\ \sum\limits_{j=k-5}^{k-2} m_{1j}>V \end{cases}.$$

For infobus 2, the conditions for determine a potential set of infobus stoppings J_{2P}, also value Δ_2, and the real set of infobus stoppings J_2 can be defined as:

$$\begin{cases} J_{2P}=\{2,3,\ldots,k\}\setminus J_1 \\ \sum\limits_{j=\sup J_{2P}-\Delta_2}^{\sup J_{2P}} m_{1j}\le V,\quad \sum\limits_{j=\sup J_{2P}-\Delta_2-1}^{\sup J_{2P}} m_{1j}>V. \\ J_2=\{j \,|\, \sup J_{2P}-\Delta_1\le j\le \sup J_{2P}\} \end{cases} \tag{7}$$

$$\begin{cases} J_{2P}=\{2,3,\ldots,k\}\setminus\{k-1,k\}=\{2,\ldots,k-2\} \\ \sum\limits_{j=(k-2)-2}^{k-2} m_{1j}\le V,\quad \sum\limits_{j=(k-2)-3}^{k-2} m_{1j}>V \\ J_2=\{j \,|\, k-4\le j\le k-2\} \end{cases} . \tag{8}$$

From condition (7), (8) it follows that $J_1=\{k-4,k-3,k-2\}$.

The essence of the formation sets of stoppings for infobuses 1 and 2 is shown in the following example.

It suppose, the capacity of the infobus is *V = 25*. There is a matrix *M_Z* at a certain moment, whose elements $m_{1k-5},m_{1k-4},m_{1k-3},m_{1k-2},m_{1k-1},m_{1k}$ have following values 5,9,8,7,9,11:

$$M_Z=\begin{pmatrix} 0 & m_{12} & \ldots & \ldots & 5 & 9 & 8 & 7 & 9 & 11 \\ 0 & 0 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & m_{2k} \\ 0 & 0 & 0 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & m_{ik} \\ 0 & 0 & \ldots & \ldots & \ldots & \ldots. & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & 0 & m_{k-1k} \\ 0 & 0 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & 0 & 0 \end{pmatrix}.$$

For the infobus 1, that transports passengers from the first stoppings, the potential set of stoppings is $J_{1P}=\{2,\ldots,k\}$. Therefore $\sup J_{1P}=k$. According to conditions (5), (6):

$$\begin{cases} \sum\limits_{j=\sup J_{1P}-\Delta_1}^{\sup J_{1P}} m_{1j}=\sum\limits_{j=k-1}^{k} m_{1j}=9+11=20\le 25 \\ \sum\limits_{j=\sup J_{1P}-\Delta_1-1}^{\sup J_{1P}} m_{1j}=\sum\limits_{j=k-1-1}^{k} m_{1j}=7+9+11=27>25 \end{cases} \Rightarrow$$

$$J_1=\{k-1,k\},\Delta_1=1.$$

For the infobus 2 the potential set of stopping will be $J_{2P}=\{2,3,\ldots,k\}\setminus J_1=\{2,3,\ldots,k-2\}$ and $\sup J_{2P}=k-2$. According to conditions (7), (8):

$$\begin{cases} \sum\limits_{j=\sup J_{2P}-\Delta_2}^{\sup J_{2P}} m_{1j}=\sum\limits_{j=(k-2)-2}^{k-2} m_{1j}=8+9+7=24\le 25 \\ \sum\limits_{j=\sup J_{2P}-\Delta_2-1}^{\sup J_{2P}} m_{1j}=\sum\limits_{j=(k-2)-2-1}^{k-2} m_{1j}=5+9+8+7=29>25 \end{cases} \Rightarrow$$

$$\begin{cases} J_2=\{k-4,k-3,k-2\} \\ \Delta_2=3 \end{cases}$$

In general case, for any infobus $\dot{n}_i$, the potential set of stoppings $J_{\dot{n}_i P}$, the value $\Delta_{\dot{n}_i}$ and the real set of stoppings $J_{\dot{n}_i}$ are determined from the following conditions:

$$\begin{cases} J_{\dot{n}_i P}=\{i+1,\ldots,k\}\setminus\bigcup J_{\dot{n}_i-1},\ J_0=\varnothing, \\ \dot{n}_i\in N,\Delta_{\dot{n}_i}=N_0, i=\overline{1,k-1},\ j=\overline{1,k} \\ \sum\limits_{j=\sup J_{\dot{n}_i P}-\Delta_{\dot{n}_i}}^{\sup J_{\dot{n}_i P}} m_{ij}\le V,\quad \sum\limits_{j=\sup J_{\dot{n}_i P}-\Delta_{\dot{n}_i}-1}^{\sup J_{\dot{n}_i P}} m_{ij}>V, \\ J_{\dot{n}_i}=\{j \,|\, j\in N_0, \sup J_{\dot{n}_i p}-\Delta_{\dot{n}_i}\le j\le \sup J_{\dot{n}_i p}\}. \end{cases} \tag{9}$$

Thus, according to system (9) a lot of real sets of infobuses stoppings $\bigcup J_{\dot{n}_i},\dot{n}_i\in N$ for the row *i* of the correspondence matrix *M_Z, Z = 1, 2,…* is formed.

This a lot of stopping sets is a delivery plan for the row *i* of the correspondence matrix *M_Z*. Indeed, the index $\dot{n}_i,\dot{n}\in N$ of the real set of stoppings $J_{\dot{n}_i}$ indicates the sequence number of the infobus, and the contents of the set $J_{\dot{n}_i}$ indicates the numbers of the stoppings at which this infobus will make delivery. A lot of $\bigcup\limits_{i=1}^{k-1}\bigcup J_{\dot{n}_i},\dot{n}_i\in N$ corresponds to the delivery plan for the entire current matrix of correspondence *M_Z, Z = 1,2, ….* The order of passenger delivery from the stopping *i* is performed by increasing the sequential numbers of infobuses that are sanded on the route.

Also, the proposed smart transport system is able to determine stopping points from real set of stops delivery $J_{\dot{n}_i}$ of infobus $\dot{n}_i$, where vehicle can after disembarking also pick up additional passengers who are going to go to his next stops of the set delivery $J_{\dot{n}_i}$. In another words, all passengers (who going to the next stopping points of real stop set $J_{\dot{n}_i}$) are taken in the vehicle from the disembarking stop of set $J_{\dot{n}_i}$, 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:

$$(0\ \ 0\ \ 0\ \ 0\ \ 2\ \ 4\ \ 6\ \ 3\ \ 7\ \ 15)$$

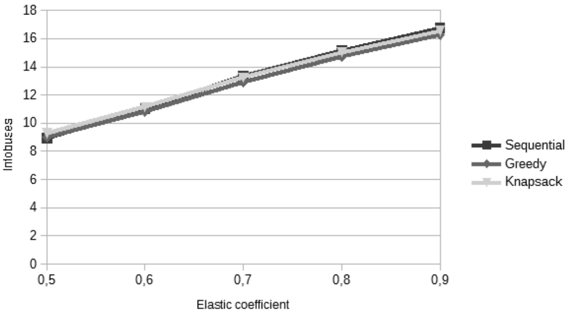
Let at this stop after disembarking of passengers the amount of available seats in some infobus with the number $\dot{n}_i$, $i<4$ is equal to 11, and real set of delivery stations is $J_{\dot{n}_i}$ = {4,5,6,7,8,9}. In this case passengers are travelling from the fourth stop to the stops {5,6,8} can 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, that draws 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 :

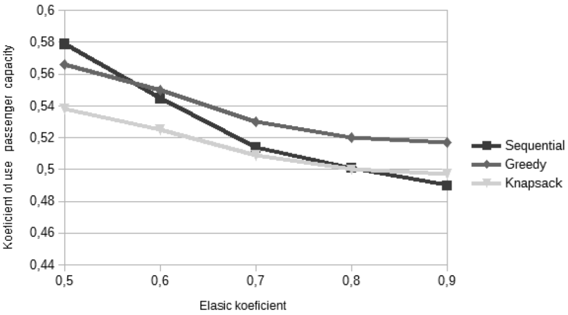
$$K_{PC} = \frac{\sum_{i=1}^{n_{span}} (1 - V_{fp_i})}{V \times n_{span}}, \qquad (10)$$

Where V- infobus passenger capacity, n_{span}- the total number of all spans (intervals between neighboring stops) on which the infobuses of delivery plan carried passengers, V_{fpi} - 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, are shown in Pic. 4 and Pic. 5.



Pic. 4. Dependence of the average infobuses number on the elasticity coefficient *a*



Pic. 5. Dependence of the average coefficient K_{pc} of use passenger capacity on the elasticity coefficient *a*

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

Conclusions

A new type of urban public transport is proposed in this article. This type of transport is capable to function in a saturation street and road traffic without interference from other vehicles also to deliver a large number of passengers that is comparable to the metro power. The transport system is closed. That means the system functions independently from human participation. The information processes (information gathering, information processing, making decision) follow continuously in such system and form its basis. The single vehicle unit in this system is an unmanned electric car is named infobus.

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РЕЗЮМЕ

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Інтелектуальна міська транспортна система, яка базується на роботизованих автомобілях

У запропонованій роботі пропонується опис інтелектуальної інформаційно-транспортної системи, покликаної розвантажити перенасичену дорожньо-транспортну обстановку в містах.

Об'єктом дослідження є безпілотні міські пасажирські транспортні системи, керовані з єдиного центру за допомогою інформаційної системи.

Метою зазначеної роботи є опис математичної моделі побудови плану перевезення пасажирів за допомогою інтелектуальної інформаційно-транспортної системи.

У процесі виконання алгоритму складання плану перевезення пасажирів здійснюється побудова спеціальної матриці кореспонденцій та обробка її з метою складання плану перевезення пасажирів на міських наземних маршрутних лініях.

Результатом виконання алгоритму є складання плану розвезення у вигляді безлічі зупинок доставки для кожного транспортного засобу, який бере участь у реалізації даного плану розвезення. Сукупність таких планів для окремих транспортних засобів утворює план розвезення пасажирів для всієї матриці кореспонденцій.

Також у роботі дана оцінка верхньої та нижньої меж необхідної кількості безпілотних транспортних засобів.

У ході тестування, результати якого наведено в роботі, показано відповідність запрогнозованим оцінкам.

Результатом запропонованої роботи є опис алгоритму здійснення міських пасажирських перевезень за допомогою інтелектуальної інформаційно-транспортної системи, заснованої на використанні роботизованих безпілотних транспортних засобів малої місткості, які називаються ІНФОБУС, які керуються з єдиного координуючого інформаційного центру. Система здатна запропонувати провізну спроможність, яку можна порівняти з метро, а також зменшити вартість проїзду й тривалість часу, що витрачається на проїзд.

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