May, 28-29, 2019, Ternopil, Ukraine

ICCPT 2019: Current Problems of Transport: Proceedings of the 1st International Scientific Conference, May 28-29, 2019, Ternopil, Ukraine

System of urban unmanned passenger vehicle transport

Vasili Shuts, Alena Shviatsova

Brest State Technical University, Moskovskaya 267, 224017, Brest, Belarus, lucking@mail.ru, helengood@gmail.com

Abstract: This article describes the system unmanned urban passenger transport based on mobile autonomous robotic vehicles. The article describes an algorithm for drawing up a non-conflicting plan of passenger transportation on demand. The relevance of this system is conditioned changing social and economic conditions in the large cities, as well as modern features of scientific and technical progress. The aim of this paper consist of improvement of quality and efficiency of passenger transport in the "loaded" urban transport environment. The mathematical model of computer control unmanned transport system is described in this work. The result of job consist of description the algorithm for organization passenger transportations using unmanned vehicles. The considered model is adaptive to changings of road conditions and intended for enhance the mobility and flexibility of passenger transport in the context of high traffic flows and also brings economic and environmental benefits, since the method of transporting passengers by unmanned vehicles provides a high throughput of urban transport systems with a high level of passenger comfort.

Keywords: intelligent transport system, information transport, unmanned passenger vehicle, mobile transport system, system of unmanned transport

1. Introduction

Personal road 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, to avoid traffic conflicts, it is need unload oversaturated road ways through the expansion of public land transport with high performance that will be 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;

Peer-review under responsibility of the Scientific Committee of the 1st International Scientific Conference ICCPT 2019: Current Problems of Transport

- 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.

2. Literature review

The last decade is characterized by active development in the field of autonomous and unmanned vehicles. Many scientific work, 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 largest modern projects in the field of unmanned vehicles VIAC (2007-10), SPITS (2008-11), HAVEit (2008-11), Cybercars-2, GCDC (2009-11), e-Safety (2002-13), DARPA and Google Driverless Car develop optimal control transition interfaces from automatic to manual mode. «There are several human factor concerns with highly autonomous or semiautonomous driving, such as transition of control, loss of skill, and dealing with automated system errors. Four CityMobil experiments studied the eLane concept for dual-mode cars, and the results of one are described» (Toffetti, Wilschut, & Martens, " CityMobil: Human Factor Issues Regarding Highly-automated Vehicles on an eLane", 2009, p. 1) [10]. Today there are five levels of autonomy for cars: lack of autonomy, when the driver has full control over the cars without any warnings or assistance; the presence of assistance systems, when the driver still has full control, but there are systems of support by signals or sound, for example, during the maneuver of the lane change; semi-automated cars, when partial control in certain situations or conditions can be delegated to the system, for example, adaptive cruise control, parking assistance; highly automated cars, when the assistance system assumes the main control tasks, but if necessary, the control can still be transferred to the driver; fully automated cars when the car is completely autonomous, even in difficult situations.

Work on Advanced Driver Assistance Systems (ADAS) is carried out in areas such as: lane change assistance systems; pedestrian safety systems; collision avoidance and warning systems; adaptive headlight control systems; parking assistance systems; night vision systems, cruise control systems; internal monitoring systems that allow the driver to detect the sleeping state and warn of a dangerous situation (Wees & Brookhuis , "Product liability for ADAS; legal and human factors perspectives ", 2005) [11], (Kasjanik & Shuts, "Mobile assistant driver in choosing a driving strategy", 2012) [12].

The next step includes the creation of cooperative adaptive cruise control systems based on V2V interaction, traffic signs recognition systems and traffic lights systems that use information from digital maps. The development of ADAS will influence on vehicle safety requirements and over time, the use of such systems will become mandatory, making the machines more autonomous. In recent years, varieties of technologies have emerged in Intelligent Transport Systems (ITS) that can change drastically our understanding of transport. In particular, large changes may occur in the near future in the organization of urban passenger traffic.

The unmanned electric shuttles with flexible control based on network technologies will play a crucial role in the megalopolises of the future, while ensuring safe, comfortable, efficient and environmentally friendly transportation. This is another important step towards the full implementation of the concept of unmanned urban public transport. Advanced software solutions and cloud services will play an important role as an integrated automotive unmanned platform. Driving is safer and more efficient. These paradigms are based on artificial intelligence algorithms that provide communication between the vehicle and the infrastructure. (Thomas & Kovoor, "A Genetic Algorithm Approach to Autonomous Smart Vehicle Parking system", 2018) [13], (Kurniawan, Sulistiyo, & Wulandari, "Genetic Algorithm for Capacitated Vehicle Routing Problem with considering traffic density", 2015)[14], (Potuzak, "Time Requirements of Optimization of a Genetic Algorithm for Road Traffic Network Division Using a Distributed Genetic Algorithm", 2014) [15], (Mulloorakam & Nidhiry, "Combined Objective Optimization for Vehicle Routing Using Genetic Algorithm", 2019) [16], (Wang, Ning, & Schutter, "Optimal Trajectory Planning and Train Scheduling for Urban Rail Transit Systems | Yihui Wang", 2016) [17].

The urban public transport will include the possibilities and features of personal transport (Anderson, Contributions to the Development of Personal Rapid Transit, 2016) [18]. 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) [19], (Baumgartner & Chu, "Personal Rapid Transit User Interface", 2013) [20], Mcdonald, S. S. (2013). Personal Rapid Transit and Its Development. Transportation Technologies for Sustainability, 831-850) [21].

In this work below a transport system is proposed that 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. This is a new way of conveyor-cassette urban passenger transport.

3. 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 [22]. The minimum safe distance between the infobuses in cassette of infobuses is controlled electronically. The cassette method of organizing the transport of passengers is a major step forward, which is comparable with applying of the transportation of goods by container method in the past century. 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.

It is necessary that the road network is, as much as possible, neutral to the traffic of the info buses. Unfortunately it is impossible make fully achieve zero impact on road users, as in the subway. However, this influence can be reduced by allocating a special lane, as is done for public transport such as a bus or trolleybus in many large European cities.

The disadvantage of this allocation of road lanes for infobuses is the reduction in the number of lanes for other road users and reduction in the carrying capacity of the highway. In addition, the intensity of the use of dedicated band is low sometimes. Hence the requirement for the width of the information bus is: it should be minimal, for example, it should be 1-1.5 meters. This choice is due by following factor: if the width of the main lane is 3-3.5 meters, than it is enough to divide this lane into two and as a result, we will get two lanes (direct and reverse) for the infobuses.

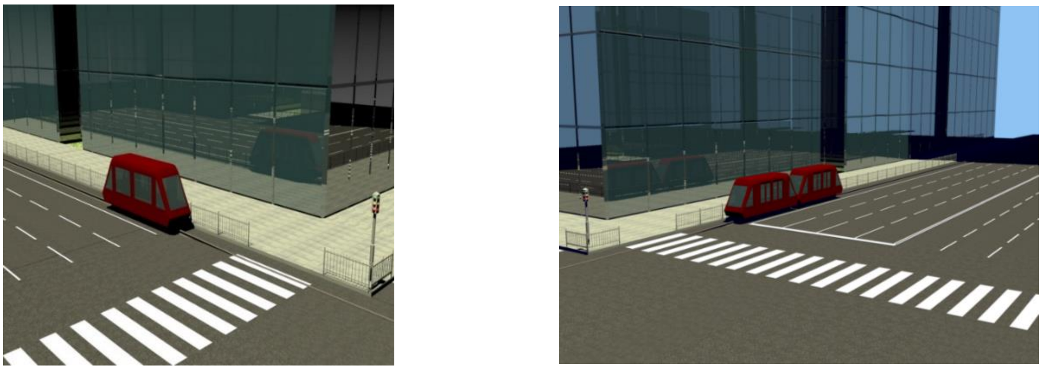

Figure 1. Auto train from one and two information buses at the intersection

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 (Fig. 1). 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 (Fig. 2).

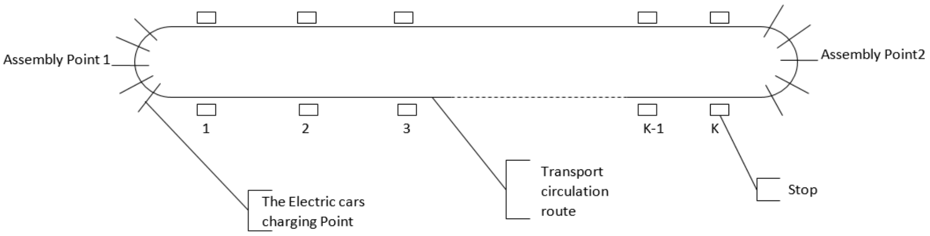

Figure 2. Infobus traffic pattern

4. System operation description

System of urban unmanned passenger vehicle transport consist of [23,24,25]:

- 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 (Fig. 2) 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, $Z=1,2,\ldots$. - is a base for the development of the transportation plan.

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 (Fig. 2). 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 [9,26,27]:

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

When a delivery plan is developing for the current matrix of correspondences M_z, $Z = 1,2, \ldots$, it is necessary to ensure conflict-free traffic on the route. A delivery plan is composed for the matrix M_z, $Z = 1,2, \ldots$, that has each element is less than the volume of the infobus V:

$$m_{ij} < V, i = \overline{1, k-1}, j = \overline{1, k}. \tag{1}$$

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, $Z = 1,2 \ldots$

- development of a delivery plan for current matrix and the implementation of this plan.

It is assumed that the delivery schedule for the current matrix of correspondences M_z, $Z = 1.2 \ldots$ begins at the time t_{0z} and ends at the time t_{kz}, that is, the duration of the delivery is $T_z = t_{kz} - t_{0z}$. Moreover, the delivery time T_z, $Z = 1,2, \ldots$ is not fixed, but depends on the data structure in the matrix M_z.

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 T_z 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 (1) of the requirement for the elements of the current matrix M_z is written as follows:

$$m_{ij} = a \cdot V, a \in (0.8,1), i = \overline{1, k-1}, \overline{j = 1, k}. \tag{2}$$

The start of development of the delivery plan is comming in the moment, when one of the elements of the M_z matrix begins to satisfy condition (2) 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.

A delivery plan is drawn up for each row separately. First, a plan is drawn up for the first row of the M_z matrix, then for the second, and so on. The implementation of the delivery plan is carried out in the same sequence, in other words, transportation of passengers begins from the first stop, then from the second, etc. The number of passengers at the first stop is the sum of the elements of the first row of the matrix:

$$m_1 = \sum_{j=1}^{k} m_{1j} = \sum_{j=2}^{k} m_{1j}.$$

For line i, the number of passengers at the stop *i* is calculated by the formula:

$$m_i = \sum_{j=i+1}^{k} m_{ij}, i = \overline{1, k-1}.$$

Then the lower range of the required number of infobuses for the export of passengers from the first stop can be estimated as the nearest integer greater than the quotient from division $\frac{m_{1j}}{V}$:

$$n_{1LR} = \left\lceil \frac{m_{1j}}{V} \right\rceil.$$

The required number of infobuses equal to the value of the lower range means that some infobuses are loaded with passengers from several neighboring destination stations. In this case, the passenger gets to the destination with a little bit number of intermediate stops (on average no more than two).

The upper range of the required number of infobuses to export all passengers from the first stop is equal to:

$$n_{1UR} = k - 1.$$

Such a case occurs on condition, that for each pair of near elements $(m_{1j}, m_{1j+1}), j = \overline{2, k-1}$ of the first row of the matrix of correspondence M_z, the condition $m_{1j} + m_{1j+1} > V, j = \overline{2, k-1}$ is satisfied, in other words passengers that go to two neighborhood stops do not fit in one bus. In other words, each infobus is loaded with passengers, which follow to the same destination station, and each passenger arrives non-stop at his destination.

For any row *i* of the correspondence matrix M_z, it is possible to immediately specify the lower and upper ranges of the required number of all infobuses are needed for export all passengers from the stop *i*:

$$n_{iLR} = \left\lceil \frac{m_i}{V} \right\rceil = \left\lceil \frac{\sum_{j=i+1}^{k} m_{ij}}{V} \right\rceil, n_{iUR} = k - i, i = \overline{1, k-1}.$$

The lower and upper ranges allow estimating the required number of infobuses to transport all passengers of the correspondence matrix M_z for a route from k stops:

$$N_{LR} = \sum_{i=1}^{k-1} n_{iLR}, N_{UR} = \sum_{i=1}^{k-1} n_{iUR}.$$

The lower and upper ranges of the required number of infobuses, which are used for export all passengers according to the matrix of correspondence M_z, give only estimated values of the parameters of transportation. But it does not answer of the question: « How it is possible to transport passengers in such a way, that the infobuses will not delay each other , when driving, and at the same moment the minimum number of infobuses were used in delivery plan of the matrix M_z, *Z = 1.2* ...?». The answer to this question is given by the algorithm for constructing a plan for carrying passengers on the route.

Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Algorithm of constructing a delivery plan of passengers on the route

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 further reasoning the moment of the beginning the execution of the delivery for row *i* will be indicated as t_{i0}, and through t_{ik} - the moment of the ending of the execution the delivery for the string *i*.

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 $\dot{n}_i \in \{1, 2, \ldots, n_i\}$ 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. 2), 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. $J_{1P} = \{2, 3, \ldots, k\}$, 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 $J_{2P} = \{2, 3, \ldots, k\} \setminus J_1 = \{2, 3, \ldots, k-2\}$ 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:

$$\begin{cases} m_{1k} + m_{1k-1} \le V \\ m_{1k} + m_{1k-1} + m_{1k-2} > V \end{cases} \Leftrightarrow \begin{cases} \sum\limits_{j=k-1}^{k} m_{1j} \le V \\ \sum\limits_{j=k-2}^{k} m_{1j} > V \end{cases}. \quad (3)$$

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 [28]: "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 $\dot{n}_i, \dot{n}_i \in \{1,2,...,n_i\}$ will be denoted as $\sup J_{\dot{n}_i P}$. The composition of the real set of infobus stoppings depends on its capacity and the number of passengers, but the stop with sequence number $\sup J_{\dot{n}_i P}$ will always be in the real set of infobus $\dot{n}_i$ stoppings: $\sup J_{\dot{n}_i P} \in J_{\dot{n}_i}$.

To determine the real set of stoppings $J_{\dot{n}_i}$ of infobus $\dot{n}_i, \dot{n}_i \in \{1,2,...,n_i\}$, the algorithm uses a value $\Delta_{\dot{n}_i}$, that represents the number of stoppings are included in the real set stoppings of infobus $\dot{n}_i, \dot{n}_i \in \{1,2,...,n_i\}$, without the stopping $\sup J_{\dot{n}_i P}$, 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:

$$\begin{cases} J_{1P} = \{2,3,...,k\} \\ \sum\limits_{j=\sup J_{1P}-\Delta_1}^{\sup J_{1P}} m_{1j} \le V, \quad \sum\limits_{j=\sup J_{1P}-\Delta_1-1}^{\sup J_{1P}} m_{1j} > V. \\ J_1 = \left\{ j \middle| \sup J_{1P} - \Delta_1 \le j \le \sup J_{1P} \right\} \end{cases} \tag{4}$$

or

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

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 condition (5), 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:

$$\begin{cases} m_{1k-2} + m_{1k-3} + m_{k-4} \le V \\ m_{1k-2} + m_{1k-3} + m_{k-4} + m_{k-5} > V \end{cases} \Leftrightarrow \begin{cases} \sum\limits_{j=k-4}^{k-2} m_{1j} \le V \\ \sum\limits_{j=k-5}^{k-2} m_{1j} > V \end{cases}.$$

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:

$$\begin{cases} J_{2P} = \{2,3,...,k\} \setminus J_1 \\ \sum\limits_{j=\sup J_{2P}-\Delta_2}^{\sup J_{2P}} m_{1j} \le V, \quad \sum\limits_{j=\sup J_{2P}-\Delta_2-1}^{\sup J_{2P}} m_{1j} > V. \\ J_2 = \left\{ j \middle| \sup J_{2P} - \Delta_1 \le j \le \sup J_{2P} \right\} \end{cases} \tag{6}$$

or

$$\begin{cases} J_{2P} = \left\{2,3,\ldots,k\right\} \setminus \{k-1,k\} = \{2,\ldots,k-2\} \\ \sum\limits_{j=(k-2)-2}^{k-2} m_{1j} \le V, \sum\limits_{j=(k-2)-3}^{k-2} m_{1j} > V \\ J_2 = \left\{ j \middle| k-4 \le j \le k-2 \right\} \end{cases}. \tag{7}$$

From condition (7) it follows that $J_1 = \left\{k-4, k-3, k-2\right\}$. 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 $J_{1P} = \left\{2,\ldots,k\right\}$. Therefore $sup\ J_{1P} = k$. According to conditions (4), (5):

$$\begin{cases} \sum\limits_{j=\sup J_{1P}-\Delta_1}^{\sup J_{1P}} m_{1j} = \sum\limits_{j=k-1}^{k} m_{1j} = 9+11 = 20 \le 25 \\ \sum\limits_{j=\sup J_{1P}-\Delta_1-1}^{\sup J_{1P}} m_{1j} = \sum\limits_{j=k-1-1}^{k} m_{1j} = 7+9+11 = 27 > 25 \end{cases} \Rightarrow J_1 = \{k-1,k\}, \Delta_1 = 1.$$

For the infobus 2 the potential set of stopping will be $J_{2P} = \left\{2,3,\ldots,k\right\} \setminus J_1 = \left\{2,3,\ldots,k-2\right\}$ and $sup\ J_{2P} = k-2$. According to conditions (6), (7):

$$\begin{cases} \sum\limits_{j=\sup J_{2P}-\Delta_2}^{\sup J_{2P}} m_{1j} = \sum\limits_{j=(k-2)-2}^{k-2} m_{1j} = 8+9+7 = 24 \le 25 \\ \sum\limits_{j=\sup J_{2P}-\Delta_2-1}^{\sup J_{2P}} m_{1j} = \sum\limits_{j=(k-2)-2-1}^{k-2} m_{1j} = 5+9+8+7 = 29 > 25 \end{cases} \Rightarrow \begin{cases} J_2 = \{k-4, k-3, k-2\} \\ \Delta_2 = 3 \end{cases}.$$

In general case, for any infobus $\dot{n}_i, \dot{n}_i \in \{1,2,\ldots,n_i\}$, 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:

$$\begin{cases} J_{\dot{n}_i P} = \left\{2,\ldots,k\right\} \setminus \bigcup J_{\dot{n}_i - 1}, J_0 = \varnothing, \dot{n}_i \in \{1,2,\ldots,n_i\}, \\ \Delta_{\dot{n}_i} = \{0,1,2,\ldots\}, \sum\limits_{j=\sup J_{\dot{n}_i P}-\Delta_{\dot{n}_i}}^{\sup J_{\dot{n}_i P}} m_{1j} \le V, \sum\limits_{j=\sup J_{\dot{n}_i P}-\Delta_{\dot{n}_i}-1}^{\sup J_{\dot{n}_i P}} m_{1j} > V, \\ J_{\dot{n}_i} = \left\{ j \middle| j \in N_0, \sup J_{\dot{n}_i p} - \Delta_{\dot{n}_i} \le j \le \sup J_{\dot{n}_i p} \right\}. \end{cases} \tag{8}$$

Thus, according to system (8) a lot of real sets of infobuses stoppings $\bigcup J_{\dot{n}_i}, \dot{n}_i \in \{1,2,\ldots,n_i\}$ 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 $\dot{n}_i, \dot{n}_i \in \{1,2,\ldots,n_i\}$ 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 $\bigcup\limits_{i=1}^{k-1} \bigcup J_{\dot{n}_i}, \dot{n}_i \in \{1,2,\ldots,n_i\}$ corresponds to the delivery plan for the entire current matrix of correspondence

M_z, $Z = 1,2, \ldots$ The order of passenger delivery from the stopping i is performed by increasing the sequential numbers of infobuses that are sanded on the route, i.e. 1,2, ..., n_i.

In this part conclusions from the research and their implications should be presented, for instance: from the practical point of view; from the scientific point of view, in the context of the literature review.

In this part of the paper the analysis of the research results should be carried out. This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

6. 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.

This work was supported by the European grant “Grant Agreement Number 2013-4550 / 001-001” for the Be-Safe project - the Belarusian Safe Roads Network in conjunction with three European universities: Sapienza University (Rome), Athens Polytechnic University and Loughborough University (England).

References

1. Kenworthy, J. R. Renewable Strategies for Cities and Regions. Urban Energy Transition (Second Edition). *Renewable Strategies for Cities and Regions* 2018; 164-204. doi:https://doi.org/10.1016/B978-0-08-102074-6.00024-3.
2. Skirkovsky, S. Organization of passenger transportation with justification of the parameters of the urban routed transport system. *Science and transport* 2006; 1(2), 97-101.
3. Dombalyan, A.; Kocherga, V.; Semchugova, E.; & Negrov, N. Traffic Forecasting Model for a Road Section. Transportation Research Procedia 2017; 20, 159-165. doi:https://doi.org/10.1016/j.trpro.2017.01.040.
4. Meyer, G.;& Beiker, S. Road vehicle automation. Cham: Springer 2014.
5. Choromanski, W.; Grabarek, I.; Kowara, J.; & Kaminski, B. Personal Rapid Transit-Computer Simulation Results and General Design Principles. *Automated People Movers and Transit Systems* 2013. doi:10.1061/9780784412862.021.
6. Chen, Y., & Li, L. Advances in intelligent vehicles. Waltham, MA: Academic Press 2014.
7. Bucsky, P. Autonomous vehicles and freight traffic: Towards better efficiency of road, rail or urban logistics? *Urban Development Issues* 2018; 58(1), 41-52. doi:10.2478/udi-2018-0022.
8. Wagner, P. Traffic Control and Traffic Management in a Transportation System with Autonomous Vehicles. *Autonomous Driving* 2016, 301-316. doi:10.1007/978-3-662-48847-8_15.
9. Friedrich, B. The Effect of Autonomous Vehicles on Traffic. *Autonomous Driving* 2016, 317-334. doi:10.1007/978-3-662-48847-8_16.
10. Toffetti, A; Wilschut, ES; Martens, MA. (4 more authors) City Mobil: Human Factor Issues Regarding Highly-automated Vehicles on an eLane. Transportation Research Record: *Journal of the Transportation Research Board* 2009, 2110. 1 - 8. ISSN 0361-1981.
11. Wees, K., & Brookhuis, K. Product liability for ADAS; legal and human factors perspectives. Возможно, вы имели в виду: ERTIR Результаты поиска Все результаты *European Journal of Transport and Infrastructure Research* 2005; 5(4), 357-372.
12. Kasjanik, V., & Shuts, V. Mobile assistant driver in choosing a driving strategy. Artificial Intelligence 2012 (Ukraine); 3, 253-259.
13. Thomas, D.; Kovoor, B. C. A Genetic Algorithm Approach to Autonomous Smart Vehicle Parking system. *Procedia Computer Science* 2018; 125, 68-76. doi:10.1016/j.procs.2017.12.011.
14. Kurniawan, R.; Sulistiyo, M. D.; Wulandari, G. S. Genetic Algorithm for Capacitated Vehicle Routing Problem with considering traffic density. *International Conference on Information Technology Systems and Innovation* (ICITSI) 2015; doi:10.1109/icitsi.2015.7437695.
15. Potuzak, T. Time Requirements of Optimization of a Genetic Algorithm for Road Traffic Network Division Using a Distributed Genetic Algorithm. *Issues and Challenges in Artificial Intelligence Studies in Computational Intelligence* 2014; 155-166. doi:10.1007/978-3-319-06883-1_13.

16. Mulloorakam, A. T.; & Nidhiry, N. M. Combined Objective Optimization for Vehicle Routing Using Genetic Algorithm 2019. Materials Today: Proceedings, 11, 891-902. doi:10.1016/j.matpr.2018.12.016.
17. Wang, Y.; Ning, B.; & Schutter, B. D. Optimal Trajectory Planning and Train Scheduling for Urban Rail Transit Systems | Yihui Wang 2016. Retrieved from https://www.springer.com/gp/book/9783319308883.
18. Anderson, E. Contributions to the Development of Personal Rapid Transit 2016.
19. Personal rapid transit. Retrieved March 02, 2019 from https://en.wikipedia.org/wiki/Personal_rapid_transit.
20. Baumgartner, J. A., & Chu, P. Personal Rapid Transit User Interface. *Automated People Movers and Transit Systems* 2013. doi:10.1061/9780784412862.019.
21. Mcdonald, S. S. Personal Rapid Transit and Its Development. *Transportation Technologies for Sustainability*2013, 831-850. doi:10.1007/978-1-4614-5844-9_671.
22. Safe Road Trains for the Environment. (20 June2018). Retrieved April 28, 2019, from http://en.wikipedia.org/wiki/Safe_Road_Trains_for_the_Environment.
23. Prolisko, E., & Shuts, V. Dynamic model of the INFOBUS transport system. In Artificial Intelligence. Intellectual transport systems. Brest: Publishing House of Brest State Technical University2016. pp. 49-54
24. Kasjanik, V.; & Shuts, V. Mobile assistant driver in choosing a driving strategy. *Transport and Telecommunication* 2012; 12(4), 52-60.
25. Persia, L.; Barnes, J.; Shuts, V.; Prolisko, E.; Kasjanik, V.; Kapskii, D.; & Rakitski, A. High capacity robotic urban cluster-pipeline passengers transport. In The International Scientific and Technical Conference "Artificial Intelligence. *Intelligent Transport Systems* (Be-Safe 2016)" Brest: Publishing House of Brest State Technical University. pp. 62-68.
26. Prolisko, E.; & Shuts, V. Mathematical model of work "INFOBUSOV". In The VII Ukrainian-Polish Scientific Practical Conference "Electronics and Information Technology (EIT-2015)". Lviv-Chinadi, Ukraine.
27. Shuts, V., & Prolisko, E. The metro alternative transport based on mobile robots. *Artificial Intelligence* (Ukraine) 2016, 2(72), 170-175.
28. Rudin, W. 1. In The Real and Complex Number Systems. Principles of Mathematical Analysis. McGraw-Hill, 1976; p. 4.