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THE CRITERION OF ARISING MOTION CONFLICT OF UNMANNED VEHICLES DURING IMPLEMENTING TRANSPORTATION PLAN IN INTELLIGENT URBAN PASSENGER TRANSPORTATION SYSTEM

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КРИТЕРІЙ БЕЗКОНФЛІКТНОГО ДОТРИМАННЯ БЕЗПІЛОТНИХ ТРАНСПОРТНИХ ЗАСОБІВ ПІД ЧАС РЕАЛІЗАЦІЇ ПЛАНУ ПЕРЕВЕЗЕННЯ В ІНТЕЛЕКТУАЛЬНІЙ ПАСАЖИРСЬКІЙ ТРАНСПОРТНІЙ СИСТЕМІ

Abstract. The proposed article is devoted to the description of an intelligent urban passenger transport system based on unmanned electric vehicles, sequentially moving along a separate line. This system is a passenger transport system of a new urban mobility, formed under the influence of social conditions generated by high population density in cities, that suppose the development of pedestrian zones and ecological modes of transport, "transport as a service", etc. In this historical context, public transport systems acquire special relevance. The described transport system belongs to intelligent systems, since it is capable of functioning in autonomous mode without human intervention, adaptively responding to changes in the dynamics of the flow of passengers during the day. Passengers are transported by electric cars, which can be combined into cassettes according to the principle of road trains based on the transportation plan drawn up by the intelligent center of the transport system according to the matrix of correspondences, filled in taking into account the incoming requests for service from passengers. When drawing up a transportation plan, the algorithms of the transport system give preference to transportation according to the "source-destination" principle, that is, when the passenger goes to the destination with a minimum number of intermediate stops, and ideally without them. The paper formulates also a criterion of arising of a conflict in the movement of vehicles, which allows to identify situations when an electric vehicle driving in front can detain vehicles following after. The work has relevance because the criterion will allow to make adjustments in the schedule of movement of vehicles and exclude the loss of time and energy that carries the transport system during braking and acceleration of electric cars, as well as to reduce waiting time and travel of passengers.

Keywords: intelligent passenger transport system; INFOBUS; transportation plan; correspondence matrix; cassette transportation; information and transport system; conflict-free movement.

Анотація. Запропонована стаття присвячена опису інтелектуальної міської пасажирської транспортної системи на базі безпілотних електрокарів, які послідовно здійснюють рух по відокремленій лінії. Описана система є пасажирською транспортною системою нової міської мобільності, що формується під впливом соціальних умов, породжених високою щільністю населення в містах, яка буде припускати розвиток пішохідних зон і екологічних видів транспорту, наприклад, «транспорт як послуга» і т. д. В цьому історичному контексті набувають особливої актуальності громадські транспортні системи. Описана транспортна система відноситься до інтелектуальних систем, так як здатна функціонувати в автономному режимі, без участі людини, адаптивно реагуючи на зміну динаміки потоку пасажирів протягом доби. Перевезення пасажирів здійснюється електрокарами, які можуть об'єднуватися в касети за принципом автопоїздів на основі складеного інтелектуальним центром транспортної системи плану перевезень, по матриці кореспонденцій, що заповнюється з урахуванням заявок на обслуговування від пасажирів. При складанні плану перевезень алгоритмами транспортної системи віддається перевага перевезенням за принципом «джерело-призначення», тобто коли пасажир прямує до пункту призначення з мінімальною кількістю проміжних зупинок (а в ідеалі – без них). Також формулюється критерій створення конфлікту руху транспортних засобів, що дозволяє виявити ситуації, коли електромобіль, що їде попереду, може затримати транспортні засоби, які йдуть за ним. Робота має актуальність, так як цей критерій дозволить вносити коригування в графік руху транспортних засобів і виключати втрати часу і енергії, які несе транспортна система при гальмуванні і розгоні електрокарів, а також знизити час очікування і поїздки пасажирів.

Ключові слова: інтелектуальна пасажирська транспортна система; ІНФОБУС; план перевезення; матриця кореспонденцій; касетні перевезення; інформаційно-транспортна система; безконфліктний рух.

Introduction

According to sociological forecasts, the process of urbanization of the human population in the world will acquire such proportions that by 2030 the urban population will account for 70 to 80 percent of all its inhabitants, which will require a principles revision of the functioning of many urban infrastructures, including urban passenger transport systems. The paradigm of urban mobility by G. Ford, based on the concept of "transport independence of households," will be replaced by the paradigm "Mobil – as-a-Service", which considers transport as a service.

In other words, in conditions of high population density, the dominant place will be occupied by public transport systems that provide comfortable transportation for passengers, comparable to a trip in private transport. The intensive development of information technologies that are combined with the increasing capabilities of computer hardware, makes it possible to effectively use intelligent algorithms to control urban transport, giving impetus to the development of intelligent transport systems[1-8].

The proposed article describes the operation principles of an intelligent transport system for urban passenger transportation, based on the use of unmanned vehicles moving sequentially along a dedicated lane, if possible, without delaying each other, and carrying passengers according to the transportation plan drawn up by the control server of the transport system based on the requests from passengers. And also the criterion is formulated that makes it possible to determine the appearance of a motion conflict of the vehicles. The motion conflict means a situation when a vehicle in front can detain a vehicle following it.

The intelligent passenger transport system and principles of its functioning

The Intelligent Urban Passenger Transportation System includes the following components:

– *stopping terminals* with the function of paying for travel and collecting passenger requests for service. Passing through the terminal, the passenger pays for the trip and indicates the stop to which he wants to go (Fig. 1).

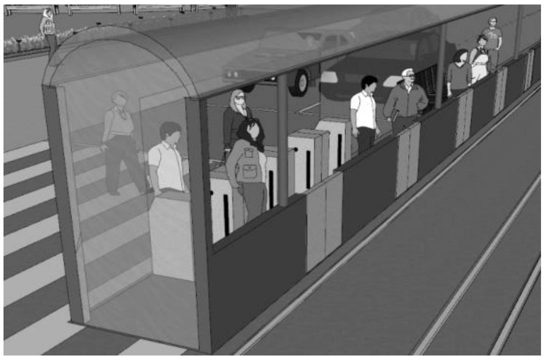


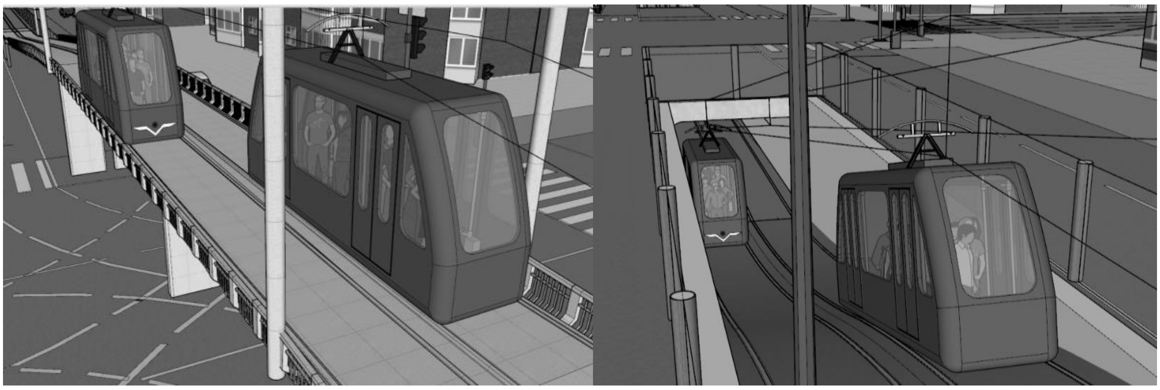
Fig. 1. Stopping terminals on station point

– *the control server* of the system that receives passenger requests from the system's terminals and records these requests in the correspondence matrix M_z (Fig. 2). Each element m_{ij} of the matrix indicates the number of passengers who made a request from stop i to travel to stop j, $i, j = 1 ... k$, where k is the number of stops in one direction of the route. The matrix of correspondences accumulates information about applications until the condition of starting the preparation of the transportation plan [9-12] occurs, after which the matrix receives a unique index $Z = 1,2,…$. The server begins to form the next matrix of correspondences and at the same time draws up a passenger transportation plan based on the fixed matrix M_z according to the selected algorithm.

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

Fig.2. The correspondence matrix M_z

– *a fleet of unmanned vehicles* are called infobuses. Infobuses move along a dedicated line (rail), thus in the case of crossing intersections along overpasses or underground tunnels, they are a high-speed type of transport with medium or high priority (Fig.3 a, b) [13].



a) on overpasses b) in tunnels

Fig. 3. The crossing ways of intersections

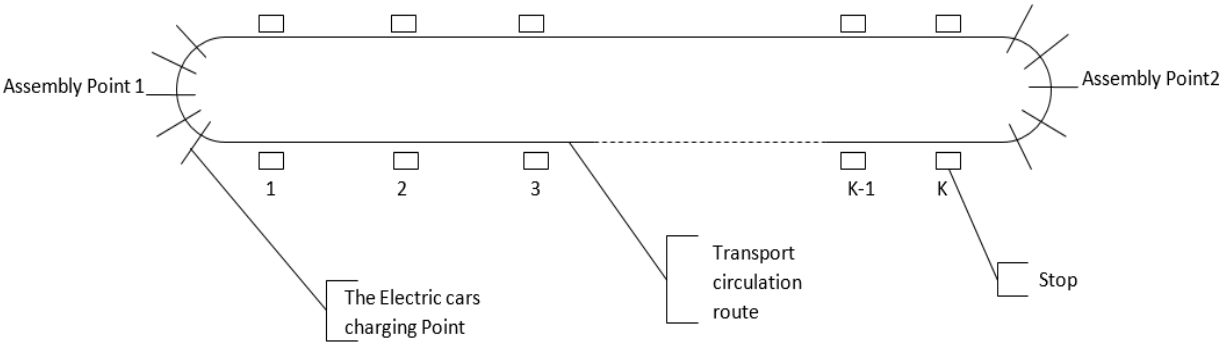


Fig. 4. Regular route of infobuses motion

– *regular route* (Fig. 4) along which infobuses move are controlled by their computer. Infobuses can move autonomously or in cassettes using virtual couplings similar to road trains [14] (Fig. 5). The infobus receives and executes the passenger transportation plan from the transport system control server

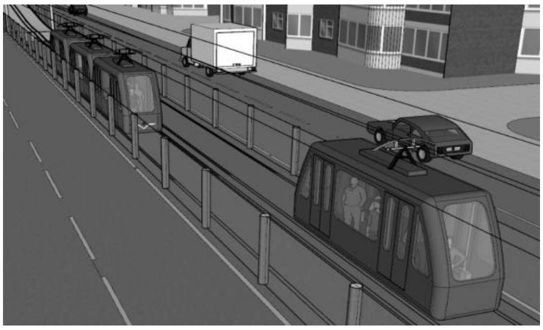


Fig. 5. Infobus and cassette

– *the passenger transportation plan* is built using the correspondence matrix Mz according to a certain algorithm depending on the current transportation volume. The passenger transportation plan is always drawn up so that only the required number of vehicles is sent to the route, slightly overlapping the volume of applications are recorded in the system by the time the vehicle appears at the stop. The passenger transportation plan implies that the infobus will receive a unique number and a set of stopping points at which the vehicle will stop [9-12, 15] for embarking or disembarking passengers.

The criteria for determining the conflict of following in the implementation of the transportation plan

Drawing up a transportation plan consists in defining for each infobus its unique identifier $n \in N$ within this plan. As well as the set of stops J_n to which it will take passengers. After receiving their transportation plan the vehicles go to the line to execute it and move sequentially one after another on a dedicated lane.

During the movement of infobuses, there may be *motion conflicts*, that is, situations when the vehicle in front detains the next one. Such conflicts are possible only on stops of the front-going infobus at which the infobus behind-going it should not stop.

Road span l_i will mean the distance between two adjacent stops *i* and *i+1*, $i=\overline{1,k-1}$.

The *idle time at a stopping point* t_{st} is the time is spent by infobuses for embarking or disembarking passengers. This value is the same for any infobus.

All infobuses move at the constant speed *v*, so they overcome the same road span at the same time.

Let's denote as $\cdot t_n^j$ the time of infobus *n* arrival according to the transportation plan to stop *j*, $j=\overline{2,k}$. This value consist of the total time is spent on overcoming previous road spans and the total time are spent on previous stops (without stop *j*). And it may be determined by the following ratio:

$$\cdot t_n^j = \frac{\sum l_{j-1}}{v} + q_n^j \cdot t_{st}, \qquad (1)$$

where $q_n^j \in N$ means the number of previous stops are made before stop *j*. The product of values $q_n^j \cdot t_{st}$ determines the cumulative time are spent at the previous stopping points before the stop *j* and will be named as *accumulated idle time on arrival*. So, the departure time from the stop *j* will be determined by the following ratio:

$$t_n^j \cdot = \frac{\sum l_{j-1}}{v} + (q_n^j + 1) \cdot t_{st}, \qquad (2)$$

where $(q_n^j+1)\cdot t_{st}$ is the time of accumulated idle time with a stop *j*. It is called the *time of accumulated idle time right after departure*.

A motion conflict occurs when the after infobus with number *n+1* appears at a station at which it should not stop according to the transportation plan and the previous infobus with number *n* has not yet left it. This condition can be described by the following ratio:

$$\begin{aligned} &\cdot t_{n+1}^j < t_n^j \cdot = \frac{\sum l_{j-1}}{v} + q_{n+1}^j \times t_{st} - \frac{\sum l_{j-1}}{v} - \\ &-(q_n^j+1)\times t_{st} = q_{n+1}^j \times t_{st} - (q_n^j+1)\times t_{st} < 0. \end{aligned} \qquad (3)$$

Using relation (3), it is possible to formulate **a criterion of arising the motion conflict** of infobuses on a dedicated lane: *the motion conflict arises when the accumulated idle time on arrival of the next infobus* (with a number *n+1*) *is less than the accumulated idle time right after to departure of the previous infobus* (with a number *n*).

For example, let's consider the situation when the direction of the route consists of seven stops (Fig. 6), i.e. $k=7$. $l_i, i=\overline{1,6}$ .. – road spans of the route. t_{st} = *20s.* All road spans are overcome during *20 s*.

Fig. 6. One route direction

Let's suppose, that for the first row of the correspondence matrix M_Z looks like

$$\begin{pmatrix} 0 & m_{12} & m_{13} & m_{14} & m_{15} & m_{16} & m_{17} \end{pmatrix}.$$

The control server has drawn up the following passenger transportation plan: infobus *1₁* will take passengers to stops $J_{1_1}=\{4,5,6\}$ and infobus 2_1 to stops $J_{2_1}=\{2,3,7\}$ (the subscript in the designation of infobuses numbers indicates the initial stop. In example case it is the first stop of the route). These infobuses leave the assembly point as a cassette and load people at stop *1*. At stop *2*, infobus 2_1 separates from the cassette for disembarking passengers, and infobus 1_1 continues to move at stop 4. The motion conflict is possible at infobus 1_1 stops, i.e. at stops $J_{1_1} = \{4,5,6\}$.

Table 1 contains formulas for calculating the arrival time for infobus 2_1 and departure time for infobus 1_1, as well as the difference between these values at stops $J_{1_1} = \{4,5,6\}$.

Table 1. Arrival/departure time at stops $J_{1_1} = \{4,5,6\}$

Station / ***Time***	***j = 4***	***j = 5***	***j = 6***
$\cdot t_{2_1}^j$	$\frac{\Sigma l_3}{v} + 2 \times t_{st}$	$\frac{\Sigma l_4}{v} + 2 \times t_{st}$	$\frac{\Sigma l_5}{v} + 2 \times t_{st}$
$t_{1_1}^j \cdot$	$\frac{\Sigma l_3}{v} + t_{st}$	$\frac{\Sigma l_4}{v} + 2 \times t_{st}$	$\frac{\Sigma l_5}{v} + 3 \times t_{st}$
$t_{2_1}^j - t_{1_1}^j$	t_{st}	0	$-t_{st}$

It can be seen from the table that at stop 5 the infobuses will be connected into a cassette, and at stop 6 there will be a motion conflict because infobus 2_1 according to the transportation plan must transit this stop. The infobuses motion chart (Fig. 7) confirms the conclusions.

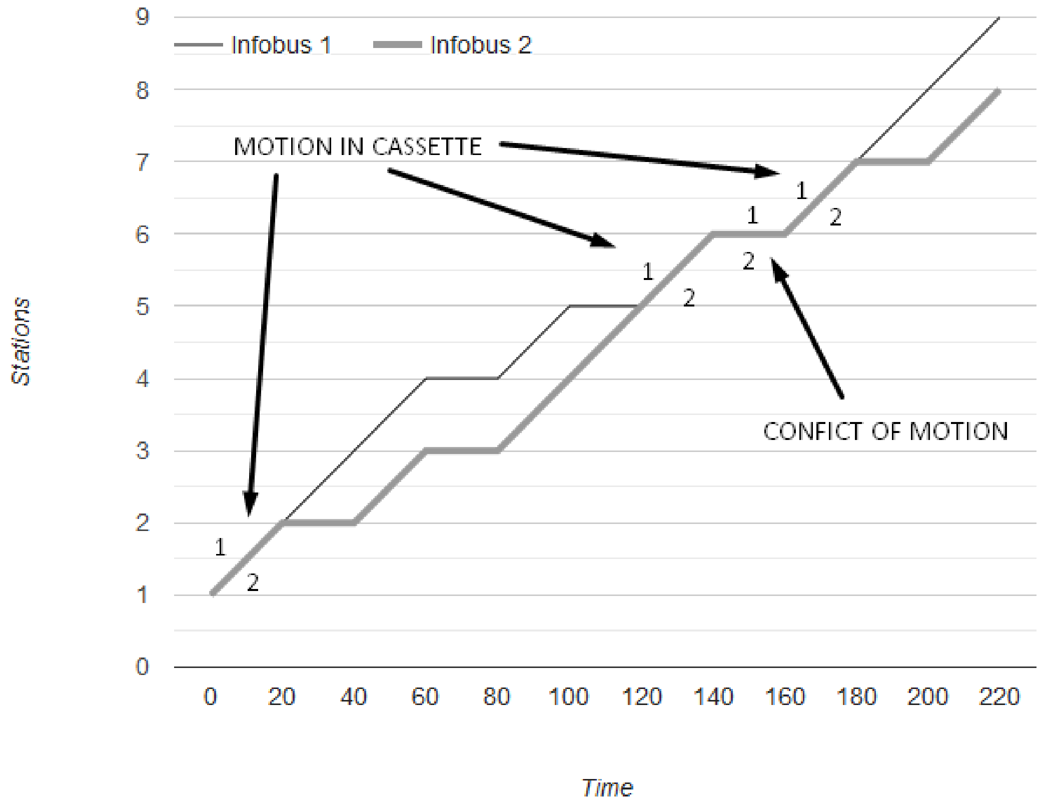


Fig. 7. The chart of infobuses motion

Conclusion

The paper formulates a criterion for the onset of a conflict situation in the movement of unmanned vehicles during implementing a transportation plan of passengers using an intelligent urban passenger transport system. This criterion allows you to identify, and therefore eliminate, potential motion delays of one vehicle by another, which gives such obvious benefits as reduced energy consumption during braking and accelerating a vehicle, the time passengers waiting at the stops, and their travel time.

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