Dynamic Public Transport in Smart City using Multi-agent system

Patrik HORAŽĎOVSKÝ, Sergey KOZHEVNIKOV and Miroslav SVÍTEK

***Abstract* —Smart City is now widely discussed and applied to all disciplines where Public transport is one of them. The aim of this paper is to define dynamic public transport in Smart City and describe transport organisation using multi-agent systems based on different data sources. Input parameters from the sensor network represent on-line demand for public transport. The better understanding of the demand for public transport the better offer can public transport operator provide to citizens. The more satisfied costumers the more attractive will be the public transport in the city. The dynamic public transport offer is computed by multi-agent system that continuously process all available on-line data and propose dynamic routes and time-schedules of different public transport means (small buses, etc.).**

***Keywords*—Public transport, Smart City, Dynamic service, Big Data, Multi-agent systems**

I. Introduction

In this time there is more and more employment and other opportunities in big cities, otherwise these opportunities disappear in small villages. Thanks to this phenomenon, people travel and they are willing to travel many kilometers to work. However, it is more convenient for them to not travel. As a result, there is worldwide effect that smaller municipalities are being depopulated and bigger cities are overcrowded [1]. This situation is beginning to become intolerable in relation to the number of people in the city, the number of vehicles – parking, congestion, emissions, pollution and another similar negative phenomenon.

The solution can be transport prohibiting in center towns or at the contrary a reward for passengers using public transport. The solution can also be to offer some sweet to a child if it uses public transport to increase its interest, but for most passengers it is essential to offer public transport, which is capacitive, fast, reliable and especially regular [2]. If the passenger will be certain that public transport will reach the destination and most importantly, he can use public transport to go back home, public transport will be a suitable alternative for him and he will use it.

Patrik Horažďovský, Faculty of Transportation Sciences, Czech Technical University in Prague, Czech Republic
Miroslav Svítek, Faculty of Transportation Sciences, Czech Technical University in Prague, Czech Republic
Sergey Kozhevnikov, CIIRC Czech Institute of Informatics, Robotics, and Cybernetics, Czech Technical University in Prague, Czech Republic

Transport planning [1] can be influenced by Smart City and Industry 4.0 trends, and this new potential can be used. Therefore, the collection of traffic data from the sensors includes automatic vehicle counting, but also Big Data [10-12], which monitors the movement of passengers not only in the vehicle, but it also tracks traffic flows and creates modal split [2].

There are still problems with transport supply of large areas with scattered villages, even though data are collected. This problem can be solved by introducing dynamics into public transport, where passengers themselves determine how public transport is served.

The aim of this paper is to introduce the new concept of dynamic public transport planning using multi-agent system design to determine the close to optimal dynamic operation of public transport in the given territory.

The paper is structured as follows: Section I defines dynamic demand model and innovative methodology of dynamic public transport area. Section II covers the description of influencing data, parameters and environment, and Section III introduces multi-agent approach to the on-line solution of dynamic public transport together with illustrative examples of agents. Section IV concludes the paper.

I. Dynamic demand model for public transport

A. Industry 4.0

Factories using Industry 4.0 must react flexibly to changing demand for products that are also significantly adapted to the individual needs of customers [3]. The transport processes for input components must also logically be adjusted to the changing demand. The logistics chain must meet the condition of "just-in-time", because large amounts of storage space are not anticipated. This can only be achieved if it is possible to guarantee transport of input components in a manner similar to the way telecommunication services are guaranteed today. In addition, it is necessary to define a quality indicator for transport, which must be constantly evaluated using information from intelligent transport infrastructure. With regard to the environment and operating conditions, we can expect greater deployment of electric vehicles, which in the future will be autonomous and driverless.

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Linking up the intelligence of transported sub-components, including guaranteed delivery time, allows for optimization and sharing of transport processes within a company. Parallel information from the production process will determine precisely when and where the given component must be used in production. This provides room for optimization under logistics so that means of transport are shared as much as possible and routes are optimized for collection and distribution of sub-components as well as waste created. The influence of Industry 4.0 on logistics will lead to better utilization of resources, infrastructure, and also space within the manufacturing enterprise. [4] It will also be possible to conduct logistics using fewer transport and handling devices, which will save a large amount of resources.

As production will adapt to demand, fluctuations in the need for workers in the manufacturing process can be expected. These fluctuations will need to be addressed through suitable and guaranteed mass passenger transport, which will have to adapt and respond to such variation. Public transport system will be used, with the schedule adapted to the requirements of the manufacturing process. Individual employees will be part of the Industry 4.0 concept and will be able to monitor the parameters of production on their smart phones along with the variable public transport timetables.

The main goal of our new concept is to transfer the main principles from Industry 4.0 to the Smart City area and adapt this concept for dynamic urban public transport system.

B. *Dynamic Urban Public Transport*

The basic idea is to create a proposal for the operation of a public transport system that will respond to actual passenger demand. In the case, it is a passenger who determines himself on the basis of predetermined rules, when and how he will be transported by public transport. The main benefit for the solved problem is the solution of the service of the mentioned small municipalities with a small number of public transport service.

C. *Shared and integrated Dynamic Public Transport*

It is important to mention, that public transport is not only about buses and trams, but it is also another types of vehicles and styles of transport. Good example is walking and cycling transport. This mode of transport is often forgotten but it has a good presumption to be an appropriate mode of transport for a “Last mile”. Especially the “Last mile” transport is a very difficult phenomenon to solve in public transport.

In region, there is many small villages with a little demand for transport. But it is necessary to ensure some public transport connections in this villages. In that case main lines of public transport have to ensure a service, so the exceptions in the timetable are created, because only in few times in a day public transport service is required. This solution creates delays and the time table is more confused for passengers. In the next figure, there is an example of the line 335 in Prague integrated transport, where the exceptions in operation are clearly visible.

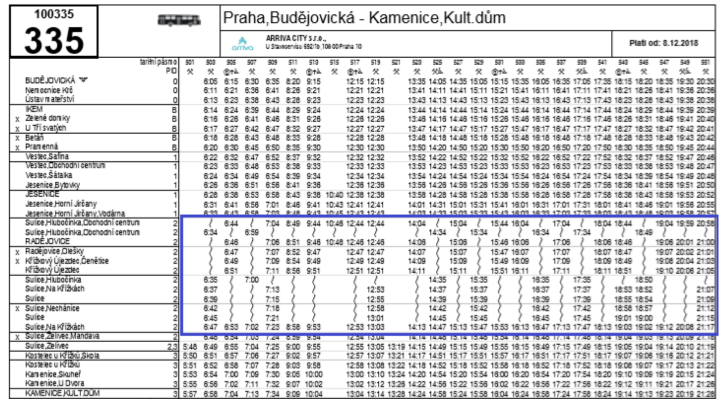

Fig.1. Complicated timetable [5]

Because of this exceptions and confusions, it is better to divide this bus line to the main line and the rest. The “rest” can be called like the Following connection which is always depended to the main lines. If it is used the same principle of public transport operation, it is necessary to create exactly defined bus lines in exact time. In this moment the problem is created, because there are many villages but with variable demand. In the result there is only few new possible connections with very long route so passengers don´t have much possibilities to use public transport or they spend a lot of time in it. So passengers do not use public transport in this regions.

In this situation is the best solution to create dynamic public transport. [6] For this type of transport, it can be used all type of vehicles or styles of transport. The bikesharing a carsharing can supplement or replaces standard bus transport – Following connection. Specifications of the dynamic public transport is not only many types of transport, it is also dynamic times of departures and variable line management on the basis of passenger requirements.

In reality, passengers can order and combine all types of transport like a following connection. Based on orders from all passengers and also based on all influenced parameters, the algorithm creates the optimal solution of transport. The solution can combine bikesharing, carsharing, walk and also standard modes of transport and respect actual state of transport around. So congestions, delays and vehicle occupancy of the main lines are respected. For finding the optimal solution the multiagent system is created.

II. ENVIRONMENT AND PARAMETERS DESCRIPTION

A. *Necessary input description*

First of all, it is necessary to understand, how the region and all transport connections can work and how can be influenced. It exists the environment, where the model solution can be implemented. [7] But the mathematical model is difficult to implement exactly to the real environment because of it´s dynamic. The environment for the agents for dynamic public transport is defined:

Inaccessible - It is not possible to reach complete information about the environment in the moment.

Non-deterministic – results are not certain and not intended.

Dynamic – the environment is changing in time.

Continuous – number of possible actions in the environment is infinite.

Non-episodic – agents don't operate in parts, they are dependent to each other.

This knowledge about environment is important to know how to specified MAS models.

Input parameters are also the main assumption to creation the multiagent system. These parameters define how the agents can respond to the environment and to each other. On the base of the reaction the optimal solution can be created.

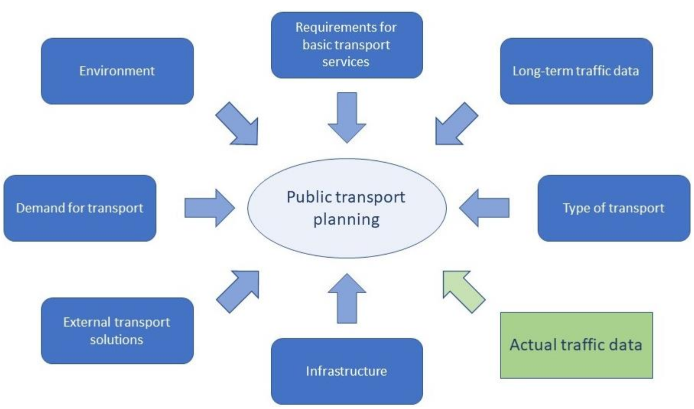

Fig.2. Source of data to transport planning.

1. *Demand parameters*

DEMAND	
Passenger	**Location**
- Time of departure - Arrival time - Travel time - Start position - Destination - Price + how much at max - Type of vehicle (bus, train, bike, Segway, walk) - Vehicle with parameter (bike transport, handicap, …) - How much time is acceptable for waiting	- Where are demanded bus stops - Where is passenger - Where is the transfer point to another transport - Where is the destination - Where is the following connection – Delay elimination

2. *Offer parameters*

OFFER	
Time	**Operating parameters**
- Departure time - Departure time of the last connection - Interval between connections (min, optimal) - Arrival time - How much time is required before following connection arrive - How much time - "delay" is tolerated if someone make a new demand when the line is already created	- Where is the vehicle - Type of vehicle (capacity) - Enough fuel? - Driver – where, can he drive (pause), driving time, … - Condition of the vehicle - Driver´s shifts

3. *Infrastructure parameters*

INFRASTRUCTURE	
Actual data [2][13]	**Infrastructure**
- Vehicle occupancy - Excess (traffic accident; traffic jam, …) - Closed roads - Dispatching restriction - Open and BIG DATA	- Road width – which type of vehicle can go through - Height limitation - Danger places

4. *Environment parameters*

ENVIRONMENT
Environment
- CO_2/km
- Temperature

How the MAS system can work in dynamic public transport is described in the next part of the text. MAS approach is discussed at the simpler solution.

III. MAS APPROACH TO DYNAMIC PUBLIC TRANSPORT

The main task – to build dynamically routes on a given graph for given values of the criteria of consistency (rationality/allowability) of the obtained solutions.

The dimension of this problem does not allow to get one global fully "optimal" solution in a reasonable time (the problem can be considered as NP - Hard). Using MAS approach we create feasible solution so called "quasi-optimal" coordinated (rational/acceptable) solutions that reflect balance of interests between all participants in the decision-making process. [8]

The model takes into account the different routes that can go through the same stops in the both directions, round routes and intersections of different routes.

On the first approximation model does not take into account different types of routes (bus, car, scooter, bicycle, walking), the capacity and flow constraint of the routes, the restriction of driving on certain sections and one way routes.

In our model we take into account the following constraints:

1) The routes can start and finish only on terminal stops.

2) We set the minimal and maximal length of routes.

3) The maximum capacity and operation price of the vehicles.

4) Ticket price.

In our model we set a fleet of vehicles, given by the types and capacity of passengers. From the very beginning we will consider 3 types of vehicles, given by their type (t), with capacity (V) parameter (further we can add more criteria - speed, comfort, etc.) and Nt –number of vehicles:

1) Personal transport $\{t_1, V_1 <2, N_{t1}\}$;
2) Sharing car $\{t_2, V_2 <4, N_{t2}\}$;
3) Micro buses $\{t_3, V_3 <15, N_{t3}\}$;

Amount of vehicles are limited with 1000 units.

We can also predefine the tariff for each type of vehicle for one passenger. The tariff is based on its own operating cost (per 1 km).

The solution of the task should be found through interactions of agents (identify conflicts, negotiate, search for acceptable solutions, iteratively improve the solution). For this purpose, we create a virtual market of the urban transport network with three types of agents:

- Order Agent.
- Fleet agent.
- Route agent.

Every agent has linear satisfaction function for all of his criteria (with values range from 0 to 1) and amount of virtual currency for dynamic rebuilding of his states. Every component of the criterion is normalized to 1. With every type of agent and his criteria, the bonus-penalty function in virtual currency is also associated. This function impacts the criteria according its deviation from the desired value. The satisfaction functions of criteria are combined into a single function with weights for each criterion, the weight can be dynamically changed by user.

The virtual currency of the routes network will be connected with the real financial flows on the virtual market of the system:

- Agents of people (stops) pay for transportation and can request the routes.
- Agents of routes build routes for people and choose a type of the vehicle of the required size.
- Fleet agents transport people and pay the operation price (amortization, gasoline, driver´s salary, etc.).

Table 1. Agents description

#	Type	Functions	Decision criteria
1	**Order agent**	Creates order agents for delivery and allocates financial resources to them. Calculates personal KPI and satisfaction level. Attempts to join an existing route in the right direction or asks the system to create a new route. Evaluates how quickly and cheaply passenger will be delivered by the route. Combines his efforts with other orders in the same direction to "attract" the best route by a big number of passengers. Pays the fleet agent.	Tries to fulfill the orders for transportation in max quantity and with most convenient and priceless way for passengers in all directions. Chooses the nearest route that transports passengers most quickly and cheaply.
2	**Route agent**	Builds the route back and forth as a sequence of stops. Input information - requests from order agents and bus agents. Calculates the time duration of route and sends the messages about time schedule to all bus stops. Under the given number of passengers on the route, the type and size of the fleet is selected. Estimates the cost of the route. Responds to the offers from the stops and decides where else he will benefit from making the loop. In the case when all participants agree, modifies it's route, takes passengers on board from the stop and recounts the economy of the route.	Trying to get the maximum profit from the transportation of passengers - planning the maximum load by the cheapest bus possible. For these purposes, it tries to go through the most advantageous stops with a minimum of distances, minimally participate in loops, minimally have common sections with segments of other routes. Tries to maximize satisfaction of groups of passengers by delivery to their desired destination in the process rebuilding the route.
4	**Fleet agent**	Provides the optimal, by size or other parameters (comfort, cost, etc.) fleet to the routes. Provides fleet first to those routes that promise to bring the maximum profit. It calculates travel time and cost for a route, taking into account its parameters for speed, number of people to load and unload at stops. It builds a timetable. Negotiate with the roads and pays for their work. If are not satisfied with the load, asks the route to change for a smaller transport.	Trying to be max loaded with passengers, min physical costs, and pass min way.

The developed method allows easily expand the number of agents, and also change or improve the functionality of the agents. [9]

The results of the multiagent modeling are presented below. Red are newly arising stops.

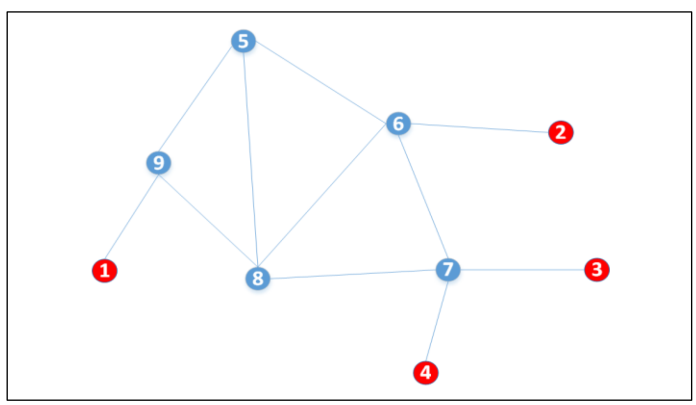

Fig. 3. Starting points of routes

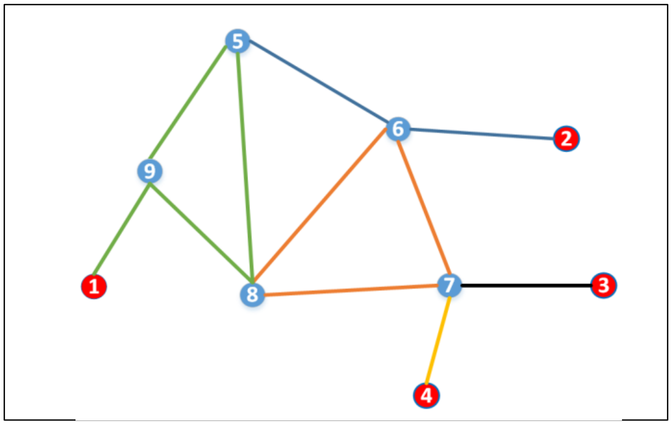

Fig. 4. Routes created after the first stage of agent's negotiation

Routes have been created:

1) 1-9-5-8-9-1
2) 2-6-5-6-2
3) 7-8-6-7
4) 4-7-4
5) 3-7-3

Routes 2) and 4) are eliminated as inefficient in length and cost, after rescheduling.

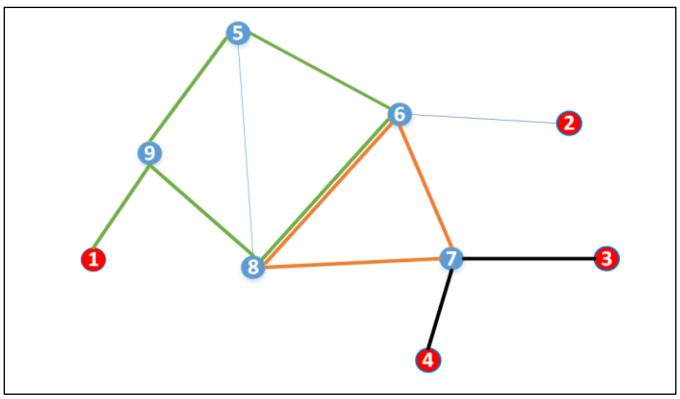

Fig. 5. Route structure after the first intervention of the city agent

The order agent increase the weight of the indicator related to the possibility of loops to the route agent 3) by raising amount of people or price in point 2.

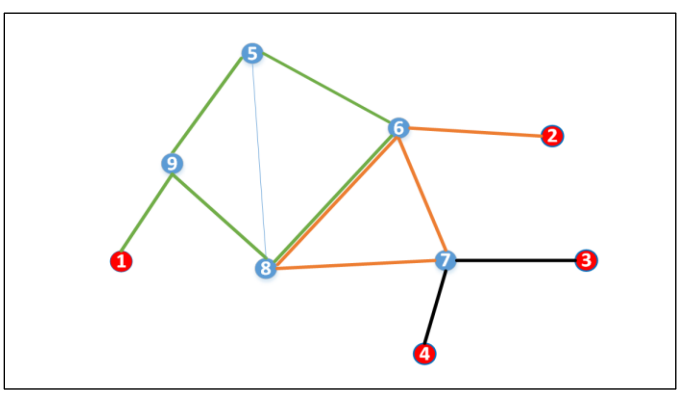

Fig. 6. Final route structure

IV. Conclusion

This article proves on the simple example, how the multiagent system can help to resolve solution of public transport service in small villages by dynamics. Agents can be edited and expanded by described parameters and be also influenced be the environment. The final transport solution can be viewed from several points of view according to the way of solving. An example may be finding a solution in relation to the price, time or another parameter and then the multiagent system compare all results to the final solution. Multiagent system can be a general mathematical tool for resolving transport services in the region.

Acknowledgment

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