Using digital twins to manage traffic flows

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Abstract. This paper explores the use of digital twins for traffic flows. Explores how digital twins can be applied to effectively manage traffic flows, including improving road safety, optimizing vehicle flow, and improving overall transportation system performance. Discusses the various technologies used to create digital twins, as well as the methods and algorithms that can be used to analyze data and make decisions based on information obtained from digital twins. The article also discusses the potential benefits and challenges associated with the use of digital twins for traffic flows, as well as possible directions for future research. This article provides useful information and recommendations for professionals in the field of transport management and technology, as well as for solving problems in the field of traffic flows.

1 Introduction

Modern cities face increasing challenges in managing traffic flows caused by an increase in the number of cars on the roads, congestion of public transport and inefficient use of infrastructure. These factors lead to traffic jams, delays and a poor travel experience for city residents.

In recent years, digital technologies and the concept of digital twins have become widespread in various industries, including transportation system management. A digital twin is a virtual model of a real object or system that reflects its state, behavior and interaction in real time. The use of digital twins in traffic flows offers new opportunities for effective management and optimization of transport infrastructure [1].

Digital twins can be used to improve road safety by proactively identifying potential hazards and preventing accidents. They can also be used to optimize vehicle flow, predict and avoid congestion and congestion, and improve the overall performance of the transportation system. Digital twins allow you to analyze a variety of data collected from various sources, such as sensors, surveillance cameras, mobile devices and transport infrastructure management systems. This allows you to make informed decisions based on real data and predict future trends in traffic flows.

However, the use of digital twins for traffic flows also presents challenges and problems. For example, it is necessary to ensure that the data used to create digital twins is accurate and up-to-date.

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In addition, it is necessary to develop effective algorithms and data analysis methods to extract valuable information from digital twins and make effective decisions.

The purpose of this scientific article is to study the possibilities of a systems approach in the design of an intelligent transport system in the region as a structural component of traffic flow management.

2 Materials and methods

Due to the growth of technological progress in large cities, there is a sharp increase in the number of both personal cars and ground transport in general, which ultimately leads to overcrowding of the transport network. To avoid such a problem, it is necessary to model a digital twin of a section of the transport network, describing the behavior on the road of both individual cars and their groups, called traffic flows.

Next, we will model a section of the road network using the software tool for developing simulation models Anylogic.

2.1 Modeling a section of the road network

Let's simulate the traffic situation at a road intersection in the AnyLogic environment [2]. Before building the model in the AnyLogic program, a computational and practical experiment was carried out at the intersection of streets in the city of Krasnoyarsk (Figure 1).

![Fig. 1. Intersection of streets in Krasnoyarsk.](image)

2.2 Experimental procedure

To conduct research on the algorithm, an experimental technique was developed [3]. The input parameters of the model are:

1. Intensity of arrival of vehicles from the northern $I_N$, eastern $I_E$, southern $I_S$ and western $I_W$ approaches, vehicles/min.
2. Distribution of cars in directions (left, straight, right) for each approach, %:
   a. for the northern approach: $p_{N\text{left}}, p_{N\text{straight}}, p_{N\text{right}}$;
   b. for the eastern approach: $p_{E\text{left}}, p_{E\text{straight}}, p_{E\text{right}}$;
   c. for southern approach: $p_{S\text{left}}, p_{S\text{straight}}, p_{S\text{right}}$;
   d. for the western approach: $p_{W\text{left}}, p_{W\text{straight}}, p_{W\text{right}}$.

The test procedure is as follows:

1. First, a test program is drawn up, based on various combinations of sequential changes in the input parameters of the model.
2. Next, for each test, the durations of the main clock cycles are calculated using the generally accepted Webster algorithm for hard algorithms.
2.1. Saturation flux is calculated:

\[ M = P \cdot n \cdot \frac{(I_D p_D^{\text{straight}} + I_D p_D^{\text{left}} + I_D p_D^{\text{right}})}{(I_D p_D^{\text{straight}} + 1.75 I_D p_D^{\text{left}} + 1.25 I_D p_D^{\text{right}})} \]  

where \( P \) – traffic lane capacity, units/hour; \( n \) – number of lanes open to traffic; \( I_D \) – traffic intensity at the considered approach to the intersection, driving units/hour; \( p_D^{\text{straight}}, p_D^{\text{left}}, p_D^{\text{right}} \) – share of cars traveling in the indicated direction, %.

2.2. The phase coefficient is calculated:

\[ y = \frac{I_D}{M} \]  

In each phase, an approach or a dedicated direction with the maximum phase coefficient, that is, the most loaded, is selected. It is the limiting one [4].

2.3. Calculation of transition cycles is performed \( t' \).

In general, transition intervals should not be scheduled to last less than 3 seconds. If the found value \( t' \) does not exceed 4 sec., then the transition interval consists of one clock cycle (yellow signal). At \( t' = 5...8 \) the transition interval must be composed of two auxiliary measures. To simplify calculations, we assume the duration of transition intervals \( t' = 3 \) sec.

2.4. The duration of the regulation cycle is calculated:

\[ T = \frac{(1.5 \cdot L + 5)}{1 - \sum y_i} \]  

where \( L \) – is the sum of all auxiliary cycles, s; \( y_i \) – phase coefficients.

2.5. The duration of the main measures is calculated:

\[ t_i = y_i \cdot \frac{T - L}{T - 1.5 \cdot L - 5} \cdot T \]  

3. The obtained values of the durations of the main measures are compiled into a separate file.

4. Next, the model is launched and in the execution mode the values of the input parameters are set in accordance with the experiment number, the operating mode of the model is “Hard Logic” and the number of the hard control logic is set.

5. After setting the parameters, the maximum execution speed is set and the moment when the average delay time reaches a stable state is recorded. When a stable state of the average delay time is reached, its value is taken and recorded in the corresponding cell of the experimental data processing sheet. Then the model execution mode is exited.

6. Next, the model is restarted, in the execution mode the values of the input parameters are set in accordance with the experiment number, the operating mode of the model is set to “Adaptive Logic”, the maximum duration of the green signal is set equal to the maximum value of the duration of the main clock cycles for the strict control algorithm, the crew time is set to 4 sec.

7. After setting the parameters, the maximum execution speed is set and the moment when the average delay time reaches a stable state is recorded. When a stable state of the average delay time is reached, its value is taken and recorded in the corresponding cell of the experimental data processing sheet. Then the model execution mode is exited.

8. Then steps 6 and 7 are repeated again with the only difference that in the first repetition the maximum duration of the green signal is set 2 sec. more, in the second - 2 sec. less and in the third - 5 sec. less.

9. Then the tests are repeated for each experiment number (steps 4...8). Thus, a complete study of the model’s performance consists of 150 runs.

10. At the end of a series of runs, the difference between the average delays of rigid and adaptive control is calculated, graphs are drawn, and conclusions are drawn.

With the help of simulation, real-life situations can be easily reproduced, sensitivity analysis of different scenarios can be performed through simulation experiments, and thus provide a better understanding of the factors affecting the system.
3 Results

The AnyLogic 6.9.0 University modeling environment was chosen as the platform for creating the simulation model [5].

The developed simulation model of work contains the following structural elements:
- four-way intersection with adjacent roads on each side;
- each road has a median strip dividing the road into two carriageways with three lanes in each direction;
- a system for generating model agents – two types of vehicles: a passenger car and a truck with a carrying capacity of 2 to 6 tons;
- four blocks of vehicle movement logic (one for each direction);
- models of light signaling elements;
- state diagram modeling the logic of switching traffic light signals based on two-ring phasing;
- a system dynamics module that models the operation of a local intersection controller;
- block and elements of model control parameters;
- module for reading rigid control cycle parameters;
- module for collecting statistics of agent parameters, a histogram of vehicle delay distribution, also showing the average delay time of all vehicles throughout the experiment.

In the model execution mode, an animation is displayed, which is a two-dimensional plan of the simulated system with vehicles moving along it (Figure 2).

![Average delay time](image)

**Fig. 2.** Model operation in execution mode.

A simulation model developed using AnyLogic can be used to support decision-making and covers all stages of conducting research using simulation modeling [6-7].

One of the key features of a transport digital twin is the presence of two-way communication between the model and the real physical object. Let's try to get data from traffic lights in real time. The simulated process is controlled using a specially created control unit shown in Figure 3.
To reverse the change in intersection regulation modes based on the simulation model, further interaction with city traffic control services is required.

4 Conclusion

In conclusion of the work done, we can say with confidence that the method of computer modeling of traffic flows, taken as the basis for assessing the throughput of elements of the street road network, based on the technology of computer modeling of vehicle movement in various road conditions, made it possible to take a new approach to the formulation and solution road capacity problems.

This scientific article conducted a study and analysis of the use of digital twins for managing traffic flows. As a result, the use of digital twins in transport infrastructure management offers many benefits and opportunities to optimize and improve transport systems.

Digital twins provide a realistic view of the health and behavior of vehicles and infrastructure in real time. They allow you to analyze large amounts of data collected from various sources and use this information to make informed decisions. The use of digital twins can improve road safety, optimize vehicle flow and improve the overall performance of the transport system.

Overall, the use of digital twins for traffic flows represents great potential for improving transport infrastructure and optimizing transport systems. Further research and development in this area may lead to the development of new innovative solutions and methods that will help cope with the problems and challenges associated with traffic flows.

References

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