Simulation modeling in GPSS for optimizing the traffic lights cycle of adjustable crossroads

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Abstract: The problem of traffic management, especially in big cities is particularly actual. Due to unavoidable motorization increase in number of vehicles has resulted in congestion, traffic jams, difficulty of the movement of pedestrians, increasing the number of accidents. Traffic jams are undesirable because of higher fuel consumption, increased pollution due to exhaust gases as well as noise, etc. The only way to avoid harmful consequences is to optimize the operation of the traffic lights cycle. The purpose of the work is creation the simulation model in GPSS for determining the optimal traffic lights cycle at adjustable crossroads when managing vehicle flows with specified intensities. The mathematical model of adjustable crossroads can be presented as a queuing system. Development of the simulation model includes several stages: programming in GPSS, verification and assessment of the adequacy. The algorithm for optimizing the traffic lights cycle and diagrams are used to find the optimal value of the cycle. The minimum intersection travel time (including time of queuing) is selected as the optimal criterion. The object of study is the traffic lights cycle regulation of the intersection Sovietskaya St. – Rogachevskaya St. – Telman St. in Gomel, Belarus. The existing traffic lights cycle regulation at the intersection Sovietskaya str. – Rogachevskaya str. – Telman str. has been studied. Simulation modeling of the intersection has been created in GPSS and traffic light cycle optimization algorithm has been developed. According to a worked out algorithm the traffic lights cycle at research intersection during saturation flux has been improved. Transport delays both at the existing and optimized crossings have been estimated. Optimization of the traffic lights cycle will

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increase the traffic capacity of the intersection, reduce the volume of toxic emissions and decrease the accident risk. The developed simulation model can be modified for other types of intersections and used as the basis for a decision support system based on low-level simulation.

Keywords: simulation modeling, adjustable crossroads, traffic lights cycle, queuing systems.

1. Introduction

Transportation is an integral part of our life. Every day, millions of people go to school, to University, to work. Public and private transport forms a single transport stream. This constant movement has become one of the symbols of all big cities. Today, megacities are full of vehicles, and roads can't cope with the growing number of cars.

The increasing concentration of the motor transport and volume of cargo transportation in cities creates a traffic safety problem and traffic jams.

Traffic jams in big cities are one of the serious questions concerning urban and traffic planning as well as organization of life and work in them. Smaller cities are not faced with that problem to such an extent, but there are periods of time when traffic jams occur as well. Vehicle delays during rush hours closely related to the arrivals to and departures from the work places as well as shopping and weekend trips. Traffic jams decrease of work capacity caused by frustration of queuing. Vehicle delays affect traffic safety, for people lose their patience very quickly and try the impossible in order to cut the time they spend on waiting.

At the same time, more than 30% of all accidents are concentrated at crossroads that occupy a small part of the city's territory. The intersection is the cause and factor that contributes to the occurrence of an accident and the full-scale observations of vehicle traffic modes indicate the need to develop and implement new methods for modeling traffic on the road network and evaluating its safety.

Thus, one of the main causes of these issues is incorrect traffic lights cycle at crossroads. Therefore, one of the ways to solve this problem is to select the optimal traffic lights cycle at intersections in such a way as to maximize their throughput.

The study of transport systems (including intersections) using simulation models is becoming more widespread due to the flexibility and visibility of the results obtained. As a result, simulation becomes a powerful tool for solving transport problems that arise in the road network.

Simulation is a research method in which the system under study is replaced by a model that describes the real system with sufficient accuracy. Experiments are conducted on the constructed model in order to obtain information about this system. Experiments on the model allow to describe the behavior of individual components of the system with the necessary level of detail, the ability to study the system in dynamics with changes in system parameters over time (Taha & Hamdy, 2007; Shevchenko & Kravchenya, 2009).

2. Literature review

There are a number of the methods allowing to optimize the operations of the traffic lights cycle.

On the one hand analytical methods allow calculating parameters of the traffic lights cycle but these calculations are made with the aid of difficult algorithms and formulas taking into account a large number of indicators.

On the other hand calculation of the traffic lights cycle is carried out by specialized program complexes, helping to operate transport streams.

Modern papers (Glimshina et al., 2017; Mochalin et al., 2017; Rasskazova et al., 2017) are devoted to the development of simulation models of intersections and transport rings in the AnyLogic system. AnyLogic has quite extensive functionality.

To assess the capacity of the existing road intersection, as well as to justify the project proposals, the authors of the paper (Burdin & Minzurenko, 2016) used a computer simulation technique

performed using the software package "Road Manager" from the company Mallenom Systems. This program complex is analogous of the software package PTV Vision.

The list of specialized packages is constantly expanding, but most of them require retraining of specialists. For this reason, papers (Barotova, 2018; Gubanov et al., 2017; Ismagilov et al., 2016; Anfilets & Shut, 2009) are dedicated to developing own software systems. For example, in (Anfilets & Shut, 2009), it is proposed to use elements of the queuing system theory and the GPSS simulation automation package to develop a model of intersections system.

In (Chen et al., 2019) is offered to assess conflicts between cars and pedestrians at intersections using an integrated microscopic simulation model. Various calibrated behavior models such as vehicle turning path, turning speed, gap acceptance model and pedestrian behavior model, were integrated into one simulation platform.

The main contributions of authors in the paper (Ferrer et al., 2019) are the following: the analysis of the importance of reliable solutions for traffic lights programs optimization; the adaptation of an iterated racing algorithm and a thorough analysis of solutions generated by means of a Genetic Algorithm, a Differential Evolution, a Particle Swarm Optimization and a Random Search.

3. Crossroads simulation modeling

The methodology of determining the optimal traffic lights cycle at adjustable crossroads includes the following steps.

Characteristic of adjustable crossroads. In the first step, the adjustable intersection is analyzed. In considering traffic indicators, it is necessary to highlight those that are most important. They include the analysis of the traffic management scheme, the traffic intensity of vehicles and pedestrians, the composition of traffic flow, the analysis of road accidents and the operation of traffic lights. Cycles and phases of traffic lights regulation are determined.

Conceptual model of adjustable crossroads. The second step is in creation of conceptual model of adjustable crossroads. The mathematical model of adjustable crossroads is presented as a queuing system (Taha & Hamdy, 2007).

Its graphic representation is shown in Figure 1. Vehicles (cars, motorcycles, public transport, etc.) arrive at adjustable crossroads and form three flows: direct movement (Figure 1 a), movement to the right (Figure 1 b) and movement to the left (Figure 1 c). Time intervals between arrivals of vehicles at crossroads have exponential distribution with intensity λ_i. Arriving vehicles are waiting in queues.

Time of intersection by vehicles has equal distribution with average value μ_i and depends on type of vehicle, possibilities of intersection without stopping, parameters of crossroads, presence of counter transport (turn to the left), presence of crosswalks (turn to the right or to the left).
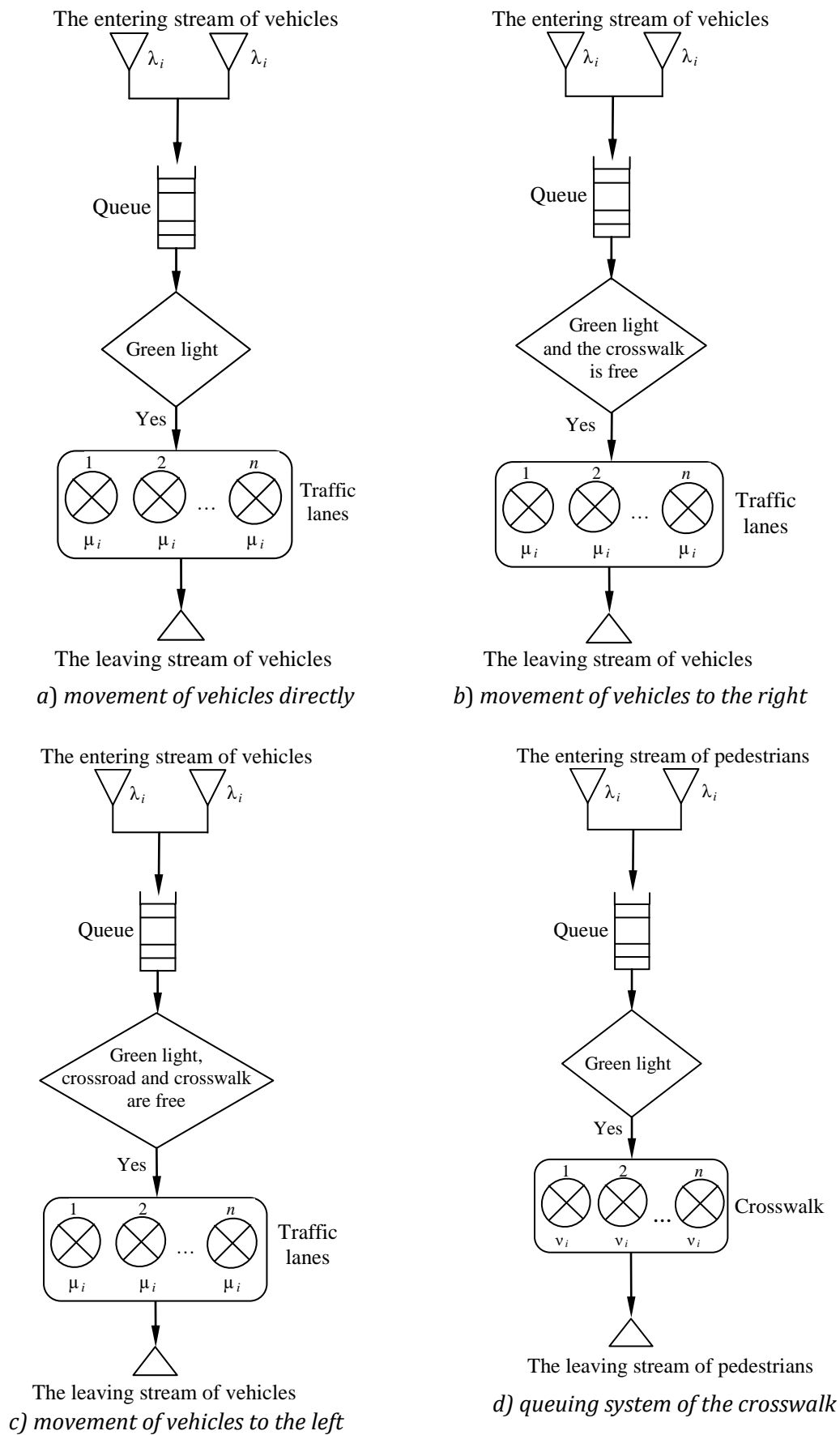
The mathematical model of crosswalk is presented in Figure 1 d.

Controlled parameters of the simulation are the intensities of vehicles of each type and pedestrians arriving at the intersection, as well as options for organizing traffic lights cycles at adjustable crossroads.

The criteria used to determine the optimal traffic lights cycle are: the average travel time of intersection by a type of vehicles, including the average downtime of vehicles; the number of vehicles that passed the intersection without stopping; the maximum and average queue lengths at the intersection; and the load factors of the intersection lanes.

The limitation of the simulation model is the simple incoming flow of vehicles and pedestrians. There are no phenomena that change the laws of the intersection travel time by vehicles. These are equipment failures, road accidents, etc.

Figure 1: Queuing systems of adjustable crossroads

The entering stream of vehicles

λ_i λ_i

Queue

Green light

Yes

1   2 n

μ_i μ_i ... μ_i Traffic lanes

The leaving stream of vehicles

a) *movement of vehicles directly*

The entering stream of vehicles

λ_i λ_i

Queue

Green light and the crosswalk is free

Yes

1   2 n

μ_i μ_i ... μ_i Traffic lanes

The leaving stream of vehicles

b) *movement of vehicles to the right*

The entering stream of vehicles

λ_i λ_i

Queue

Green light, crossroad and crosswalk are free

Yes

1   2 n

μ_i μ_i ... μ_i Traffic lanes

The leaving stream of vehicles

c) movement of vehicles to the left

The entering stream of pedestrians

λ_i λ_i

Queue

Green light

Yes

1   2 n

v_i v_i ... v_i Crosswalk

The leaving stream of pedestrians

d) queuing system of the crosswalk

The queuing system (Figure 2) is used to organize cycles and phases of traffic lights control.

Figure 2: Light cycle
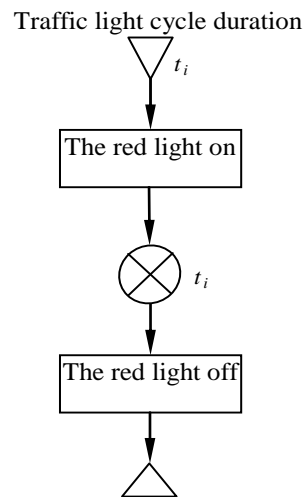
Figure 3: Algorithm for optimizing the traffic light cycle
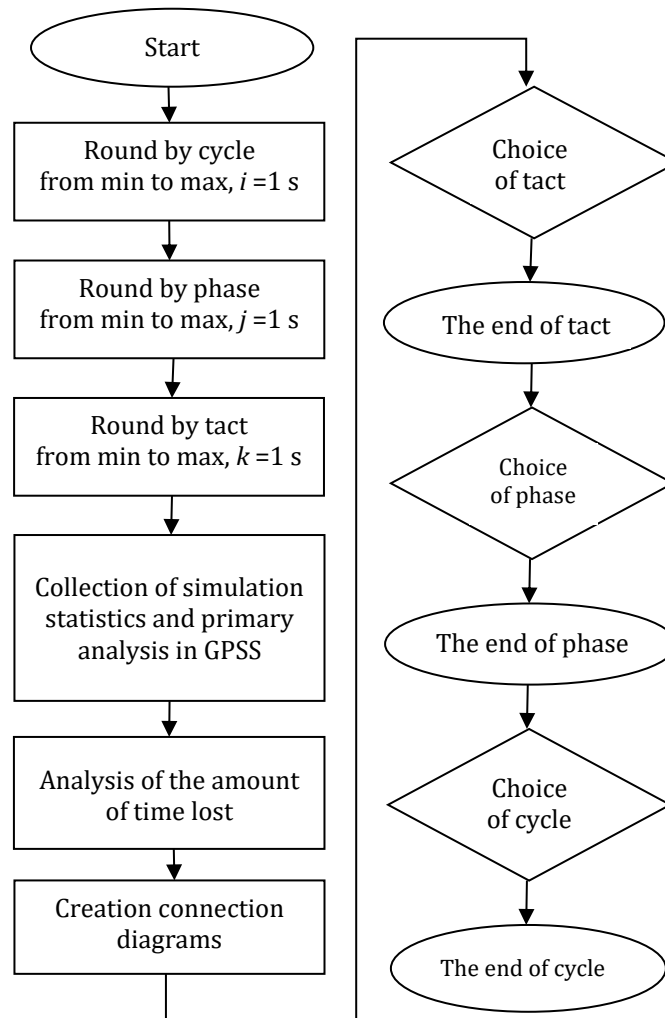
Simulation modeling in GPSS World. The next step is creation the simulation model of adjustable crossroads using GPSS World system (Taha & Hamdy, 2007; Shevchenko & Kravchenya, 2009) and execution a number of experiments on the constructed model in order to determine the optimal operation of the traffic lights cycle when controlling traffic flows with specified intensities.

The simulation model test includes two phases: verification and assessment of the adequacy. At the verification phase it is necessary to confirm the accuracy of the operation algorithm of the simulation model, using interactive capability of the model single-step debugging that allows to set control points in the model and provides opportunity to define parameters of service requests. Through verification it is possible to determine the validity of the model logical framework.

Adequacy of the simulation model to the study object is verified by concurrency with predetermined accuracy of the simulation model operation characteristics with the data obtained by analytical techniques of calculation.

Optimizing the parameters of the traffic lights cycle. When optimizing the parameters of the traffic lights cycle (Figure 3), the initial step is to iterate over the cycles of the traffic lights control cycle, taking into account the minimum and maximum cycle values.

In the process of collecting simulation statistics in GPSS determines: average queues at the intersections, vehicles downtime and lane load factors. Then, for each lane, the amount of time lost in queues is found. Diagrams of the relation between traffic lane loading and time lost in queues are constructed.

Analyzing the diagrams, the optimal tact of the traffic lights cycle is selected. Next, the phases of the traffic lights cycle are selected according to the same principle. As a result, the optimized traffic lights cycle of the intersection is determined.

4. Application

The city of Gomel with around 530,000 inhabitants is the administrative center and the second-most populous city of Belarus. Adjustable crossroads which is the topic of this paper is the intersection of Sovetskaya, Rogachevskaya and Telman Streets. Sovetskaya Street is one of the central streets in Gomel and belongs to A category. The passing capability is about 40% of routes of public transport, with no cargo vehicles. This intersection has four entrances. Entrance I (Telman St.) has three lanes, entrance II (Sovetskaya St.) has seven lanes, Entrance III (Rogachevskaya St.) – four lanes, Entrance IV (Sovetskaya St.) – seven lanes. Entrances I, II and III have regulated crosswalks; entrances I is a one-way road; entrances III, IV have one right-turning lane each and entrances II has one left-turning lane; entrances I, II and III have objects of an attraction for the pedestrian flow: that is the Gomel department store, fast food restaurant McDonald's, a set of industrial and grocery stores, and also drugstores and the medical centers, stopping points.

The regulation cycle at crossroad of Sovetskaya St. – Rogachevskaya St. – Telman St. is 84 seconds and includes 3 phases. The switching of reserve programs is made during rush hours.

The mathematical model of the adjustable intersection Sovetskaya St. – Rogachevskaya St. – Telman St. in Gomel is described and presented as a queuing system and realized in GPSS World. For the analysis of the simulation model raw data about streams of vehicles and pedestrians have been received by monitoring the operation of the intersection during the period from 7:00 till 8:00 and from 16:00 till 18:30. The research of raw data of the developed simulation model is conducted.

According to the algorithm the traffic lights cycle at the intersection Sovetskaya St. – Rogachevskaya St. – Telman St. during saturation flux has been improved.

During the time period 7.00-8.00 one optimal traffic lights cycle was adopted, the duration of which was 82 seconds: the duration of the 1st phase – 45 seconds; the duration of the 2nd phase – 23 seconds; the duration of the 3rd phase – 14 seconds.

During the time period 16.00 – 18.30 two alternative optimal solutions were selected.

In one cycle of traffic regulation has not changed, but changed the duration of the phases: duration of the 1st phase – 47 sec; duration 2nd phase – 23 sec; duration of the 3rd phase – 14 sec.

In the second version the cycle time decreased to 80 seconds, the values of the phases were as follows: duration 1st phase – 42 sec; duration 2nd phase – 25 sec; duration of the 3rd phase –13 sec.

The lowest total economic losses from vehicle and pedestrian delays are observed in the first version of the optimized traffic lights cycle.

For the optimal cycles the average downtime and average queues decreased, the number of vehicles that passed the intersection without stopping increased.

However, it was not possible to completely solve the problem of congestion at the intersection.

Analyzing results of modeling, it is possible to draw a conclusion: during rush hours jams appear arise in the morning moving down Sovetskaya Street to the downtown and at the turning to the left in Rogachevskaya Street, in the evening – down Sovetskaya Street in both directions and at the turning to the left in Rogachevskaya Street.

Conclusions

The simulation model of adjustable crossroads allows to:
– improve the modes of traffic lights,
– select the optimal values for the duration of cycle and phases for different intensities of vehicle traffic;
– analyze the traffic lights cycle depending on the time of the day, the day of the week and season;
– obtain simulation results for different types of vehicles;
– consider the possibility of allocating a lane for public transport;
– consider various distribution laws of the entering and servicing stream of vehicles.

Optimization of the traffic lights cycle will provide uninterrupted traffic, absence of traffic jams and convenience of pedestrians.

It is advisable to improve the developed simulation model of adjustable crossroads. The model can be used as the basis for a decision support system based on low-level simulation. Creating such a system let to offer options for organizing and reorganizing traffic schemes, justify the appropriateness of decisions and, as a result, reduce costs when designing transport infrastructure. In particular, the use of a simulation model will allow evaluating the effectiveness of options for organizing or reorganizing traffic, and the use of traffic lights at intersections, which is relevant for streets in large cities.

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Citation information

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