Simulation of purposeful movement in the transport network

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Abstract. A conceptual model of purposeful movement on the oriented graph of the route of the road network is presented. To determine the purpose of the movement and to stimulate the participants of the movement, two functions for calculating losses are proposed. For routing used the samples. The graph of one of the routes of Omsk was constructed using the technology of geoinformation systems. The simulation model has been developed on JavaScript. A brief description of the simulation model and the experimenter's window is given. The new results of experiments showing the influence of the target parameters, loss functions, the samples on the time and cost of moving along the route are presented. The complex relationships between the input and output data of the model are shown. The results obtained are considered from the point of view of the general problems of organizing a purposeful movement, such as goal selection, decision-making, coordination of the interests of the organizers and participants of the movement. The conclusion is made about the possibility of using the developed methods and tools for the analysis of purposeful movement in different spheres of activity.

1. Introduction

Purposeful movement (PM) is present in many areas of life. With an external conscious or unconscious influence, chaos can also be purposeful. General problems of goal achievement are studied in sociology, economics, psychophysiology [1], and mathematical game theory. The interests of technical sciences are usually related to the specific issues of the organization of the PM of specific objects.

Usually, PM occurs under the influence of random, non-formalized factors. Therefore, for the analysis of a PM, software simulation is well suited, which has almost unlimited possibilities for representing objects at different levels of detail. Oriented graphs are convenient models for many types of a PM. Simulation of a PM on oriented graphs is used in the analysis of social networks, the epidemic of biological and computer viruses [2], routing in data transmission networks and in the transport networks [3]. The author of the article used oriented graphs and simulation modeling to analyze well-known practical decision-making procedures for achieving goals in matrix games, chess, data transmission networks, and transport networks. The results obtained can be useful for solving general problems of the organization of a PM.

The article describes the use of a simulation model of the movement of cars along the route graph for the analysis of such topical issues as the choice of goals and trajectories, management procedures,
coordination of the interests of participants and organizers of the movement. There are many ways to choose the direction of travel. The article examines the procedures for selecting a line originating from a node using the target function and samples. The algorithms developed by the author of the article for using samples for decision-making are based on the methods of data analysis and classification of objects described by Zagoruiko N. G. [4].

2. Problem statement, conceptual model
It is necessary to modify the previously developed conceptual and simulation models [5] in order to eliminate the identified shortcomings and improve the quality and convenience of conducting experiments, continue the simulation experiments described in [5], [6]. To investigate the possibility of using the results of car traffic modeling to solve the problems of the organization of a PM in other areas of activity.

In this paper, the transport network was used as an experimental object for analyzing general problems of a PM. Therefore, the main requirement for the conceptual model was the possibility of using it for various systems. Previous versions of the conceptual model are described in [5], [6].

A oriented graph of a route is constructed based on the transport network. The arc of the graph has two fixed parameters:

- $L$ – arc length. Used to calculate the cost of moving and the time of free mileage $T_1$;
- $T_2$ – arc travel time equal to the sum of $T_1$ and the delay time at the traffic light.

During the simulation, $T_2$ is incremented by a random function. This is how the influence of the external environment on the driving time is modeled.

The target of PM is defined as reaching the final vertex with minimal losses. Figure 1 shows the functions for calculating $F_{p1}$ and $F_{p2}$ losses.

The target area is set as purpose = \{Xp1, Xp2, R1, R2\}.

- $Xp1$, $Xp2$ – coordinates of the target point.
- $R1$ – the radius of a small circle with the center $Xp1$, $Xp2$.
- $R2$ – the radius of a large circle with the center $Xp1$, $Xp2$.

The parameters $T$ and $C$ can be interpreted in different ways. In the article, this is the time and cost of movement along the route.

The result of a single movement of the car along the route is displayed as a point with the current coordinates $T$ and $C$. A circle with a small radius $R1$ sets the area with minimal losses ($Loss=0$). For the
Fp1, Fp2 functions, this area is colored dark gray. The area with average losses (Loss=1) is defined by circles with a small radius R1 and a large radius R2. For the Fp1, Fp2 functions, this area is colored light gray. The area with the maximum losses (Loss=2) is not filled in. Losses can have different metrics and interpretations. The main difference between the loss functions is that Fp2 follows the principle of "less is better", while Fp1 sets limits, usually closer to reality, defines the goal more precisely, and gives more opportunities for managing of a PM.

At the node, the choice of the arc to movement is based on the sample. It is necessary to distinguish between a sample and a standard. The standard is sometimes far from reality. One sample is set for all arcs. The parameters of the sample should not only reflect the specifics of the transport network, but also be interpreted for other applications. Seven parameters were selected for the sample:

\[ \text{sample} = \{ X_{s1}, X_{s2}, X_{s3}, X_{s4}, X_{s5}, X_{s6}, X_{s7} \}. \]

- \( X_{s1} \) – the average loss value.
- \( X_{s2} \) – loss at the last implementation.
- \( X_{s3} \) – the intensity of arc usage. The smaller the \( X_{b3} \), the more often the arc is selected.
- \( X_{s4} \) – average travel time along the trajectories.
- \( X_{s5} \) – the time of the last movement along the trajectory.
- \( X_{s6} \) – the average cost of movement along the trajectory.
- \( X_{s7} \) – the cost of the last movement along the trajectory.

The parameters of the sample are set before starting the model. The simulation can be performed with any set of sample parameters. After determining the parameters, the sample is a point in space.

When executing the model, the current values of the parameters are calculated for each arc:

\[ \text{Bi} = \{ X_{b1}, X_{b2}, X_{b3}, X_{b4}, X_{b5}, X_{b6}, X_{b7} \}. \]

- \( X_{b1} \) – the average loss value for the trajectories that passed through the arc.
- \( X_{b2} \) – loss on the last use of the arc.
- \( X_{b3} \) – estimation of the intensity of arc usage. The smaller the \( X_{b3} \), the more often the arc is selected.
- \( X_{b4} \) – the average travel time along the trajectories that passed through the arc.
- \( X_{b5} \) – the time of the last movement along the path passing through the arc.
- \( X_{b6} \) – the average cost of movement along the paths that passed through the arc.
- \( X_{b7} \) – the cost of the last movement along the path passing through the arc.

The current arc parameters define a point in space. In the node, the arc with the minimum distance from Bi to sample is selected for movement.

The arc may fall into a statistical "trap". This is a situation where the arc accidentally showed a very long time of movement. After that, the arc is not selected for a long time. In this case, the "rehabilitation" algorithm is started, in which the arc is selected first for transmission. This allows you to "correct" the statistics for the arc.

3. Simulation model

Most often, simulation models of transport systems are programmed in the VISSIM environment (a specialized system for large networks), AnyLogic, and GPSS. The conceptual model described above is implemented in JavaScript. The user window of the simulation program (Sim_move) is shown in Figure 2.

The Frame 1 window shows a graph of one of the routes in Omsk. The route starts at vertex 1 and ends at vertex 21. The graph is constructed by means of geoinformation systems technology [5], [6]. At the input of the Sim_move program, a directed graph of any topology can be specified. At any given time, one car moves through the graph (red dot). After the car reaches the final node, the next car starts moving at the

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initial node. The effect of pedestrian crossings and other vehicles (queues, traffic jams) is simulated by modifying the delay time by a random function.

Figure 2. The window of the experimenter

In the Frame 2 window, you can set the type of the loss function (Fp1 or Fp2).

In the Frame 3 window, the parameters of the sample are set. Some parameters may be excluded from the sample.

In the Frame 4 window, the simulation time is set in the form of the number of passes of the route by cars (Nr), normalization coefficients (k_pur, k_in) to bring the parameters of the sample to the same range.

In the window of Frame 5 records the current values during the simulation and the average values at the end of the simulation for the entire graph (ALL) and the paths passing through the bridges (arcs 8 – 15, 8 – 6, 3 – 5). In the table Num – the number of remaining implementations before the end of the simulation, T_m – the time movement on route, Sm – cost route, Loss – loss value, Rres – distance from the zero point to the point with coordinates T_m, Sm, Loss.

The Frame 6 window shows the loss functions. In the simulation, the result of movement each route is displayed as a dot. The color of the point corresponds to the color of the arc along which the trajectory passed (Frame 5).

You can stop the model execution (Stop), change the input parameters (Change), and start the simulation again (Start). After the end of the simulation, in addition to the data from the Frame 5 window, you can view more detailed results in the datasim.mdb database.
4. Results of simulation experiments

The purpose of the experiments was to analyze the influence of the composition and values of the input parameters on the output data, to search for combinations of parameters that allow achieving the set goals.

Each of the seven parameters of the sample has a different effect on the average route travel time (T_m). The diagram in Figure 3 shows how the composition of the parameters of the sample affects T_m. The gray columns show the value of T_m (in minutes) if one of parameters of the sample is missing. The number 0 means that all parameters of the sample were used in the experiment. Analysis of the gray columns allows us to conclude that the absence of any one parameter in the sample, except for Xs5, has a weak effect on T_m. The white columns show the T_m value when only one parameter is present in the sample. The number 0 means that the sample was not used for making decisions in the experiment, the choice of the arc was made only on the basis of the "rehabilitation" algorithm. The analysis of the white columns allows us to conclude that the influence of the sample parameters on T_m can be very different. In general, the diagram shows a large value of the Xs5 parameter.

![Figure 3. The influence of the parameters of the sample on T_m](image)

Figure 3 shows the effect of the Xp1 target point coordinate on T_m (left part of the figure) and on the average loss value (right part of the figure). The graphs are plotted for the loss functions Fp1 and Fp2.

![Figure 4. Effect of Xp1 on Tm loss value](image)

All experiments were performed with the parameters:

- sample = \{0, 0, -, -, 0, -, -\};
- purpose = \{var, 50, 5, 15\}.

Variable was only the parameter Xp1. Preliminary experiments have shown that such a set of parameters allows us to obtain smaller values of T_m. The right part of Fig. 4 shows for Fp2 a natural decrease in losses with an increase in Xp1. Fp1 behaves more difficult. Experiments with varying composition and parameter values have shown that the minimum values of T_m are about 38 minutes. Therefore, at Xp1=35, the points most often fall into the area of small losses. As you move away from this point, the losses increase. This is clearly shown in Figure 5. What is important is that at Xp1<35, the losses for Fp1 and Fp2 are the same. The left part of Figure 4 shows the complex dependencies between
Xp1 and T_m for Fp1 and Fp2. At Xp1<30, the losses for all arcs are equally large. Therefore, they do not affect decision-making. Arcs are only selected based on Xs5. At Xp1>40, the parameters Xs1, Xs2 first "interfere" with making the right decisions, and then the arc losses for Fp1 become equally large, for Fp2 equally small. In both cases, the arcs start to be selected based on Xs5.

![Diagram](image)

**Figure 5.** Distribution of points over the loss area

The data in Figures 4, 5 can be interpreted at the level of general problems of the PM, such as the choice of goals, compromises between the organizers and participants of the PM, the organization of ways of rewards and penalties. Let's assume that the loss means a reduction in the prize that the organizer pays to the participant of the PM. Then the goals in terms of the amount of rewards for the PM participant and the PM organizer are opposite. On the other hand, they both tend to decrease T_m. Therefore, the points of acceptable compromise are located near the coordinate Xp1=35. At these points, the T_m value is quite small and the loss functions Fp1 and Fp2 diverge.

5. Conclusions
The developed Sim_move simulation program is not focused on solving specific practical problems of road traffic. Despite this, after the necessary modification, tuning to a specific modeling object, it can be used to support decision-making on the development of the transport network of a large city. In this paper, road traffic is an experimental object for the development of a more general model of PM in various fields of activity. The developed model and the results of the experiment illustrate some common problems of the PM organization, such as decision-making, coordination of the interests of the organizers and participants of the process, setting goals, and encouraging performers.

The results of this and previous works of the author showed the feasibility of using loss functions (prizes) and samples for selecting arcs originating from the node and organization of the PM.

In the model, the dependencies of the output parameters on the input parameters are very complex (as is often the case in reality). Therefore, the search for combinations of parameters that give the desired result is very time-consuming. In the future, it is planned to partially automate this process. The main task is to expand the scope of the developed models.

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