Simulation of purposeful movement on the example of moving cars along the route graph

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Abstract. The main topic of the article is the actual problem of organizing purposeful movement. The problems of coordinating the interests of organizers and participants of the movement, building incentives, goals, and decision-making procedures are considered. A simulation model of cars movement along the route graph has been developed. The route graph is linked to the map of Omsk. Simulation experiments were conducted. The simulation model is implemented in JavaScript. The model uses a prize function and a sample for routing. The results of simulation experiments demonstrating the influence of the sample parameters and the prize function on the time and cost of achieving the goal, the value of prizes are presented. The developed simulation program can be used to analyze purposeful movement along a directed graph in systems for various purposes.

1. Introduction

Purposeful movement is the subject of research for many fields of science and technology: philosophy, mathematics, physics, biology, medicine, psychology, pedagogy, sports, Economics, sociology, politics, military Affairs, management theory and decision-making. Objects of movement can be, for example, molecules, motor functions of human and animal organs, migration of plants and animals, movement of finance, and technical objects. Thousands and millions of results are given out on the Internet for any of these directions. If restrict the theme of transport networks simulation, the most common works is related to the use of VISSIM concepts. The VISSIM system is focused on simulation of large networks (road, rail, water, and logistics). Example of such work can be [1]. The problems of purposeful movement are closely related to the tasks of searching for goals [2].

The author of the article develops methods for organizing purposeful movement on oriented graphs. The target function and samples are used to select the direction of movement. The main method of analysis is software simulation modelling. The objects for research are data transmission networks [3] and the moving cars along the route graph [4]. The procedures for using samples for decision-making are based on the methods of data analysis and object classification described by N. G. Zagoruiiko [5]. Analytical and simulation modeling is often used for analyzing transport networks [6], [7]. Different simulation programs and systems are used to build simulation models. The most popular ones include GPSS, AnyLogic, and VISSIM. In the presented work, the simulation model is programmed in JavaScript. Its main advantages are the availability of the built-in Internet Explorer interpreter, and great visualization capabilities.
2. Problem statement, conceptual model

To conduct new experiments, it is necessary to modify the conceptual model and the program for modeling the movement of cars along the route graph (Sim_move) [4].

It is necessary to formulate the task of analyzing the relationship between the parameters of prize functions and samples with the target indicators of purposeful movement.

It is necessary to conduct simulation experiments to obtain dependencies between the studied parameters, to show the possibility of using prize functions and samples for choosing routes.

The route is represented by a graph consisting of vertices connected by directed arcs. A vertex can be initial, final, intermediate, current, or neighboring. The starting vertex is the first in the route. The route ends at the final vertex. Intermediate vertices are located in the trajectory from the initial vertex to the final one. In the current vertex, a decision is made about the direction of movement. The next vertex is the one connected by an arc to the intermediate vertex. A vertex can have several qualities at once. For example, the starting vertex can be the current vertex. The main parameters of a vertex are its number, the numbers of outgoing arcs, and the number of visits.

Arches have a direction and connect adjacent vertices. Direction eliminates cycles and ensures that the goal is reached. An arc can be a model of a direct connection, a sequence of vertices, or replace a graph that connects neighboring vertices.

The main parameters of the arc i are: the time of moving along the arc Ti, the intensity of the INi selection, the cost of moving Ci, and the prize obtained as a result of selecting the arc Pri.

To calculate the prize after passing the route, two functions are used, graphically shown in figure 1.

![Figure 1. The goal and the prize](image-url)
The goal and prize for achieving the goal are set as follows: purpose = \( \{ X_{p1}, X_{p2}, R_1, R_2 \} \), where
- \( X_{p1} \) – travel time on the route.
- \( X_{p2} \) – cost of moving along the route.
- \( X_{p1}, X_{p2} \) – coordinates of the target point.
- \( R_1 \) – radius of a small circle with the center \( X_{p1}, X_{p2} \).
- \( R_2 \) – radius of a large circle with the center \( X_{p1}, X_{p2} \).

For figure 1 parameters \( T \) and \( C \) - time and cost of the route. Each passing route is characterized by a point with coordinates \((t, c)\), which are the current values of \( T \) and \( C \). Two functions are used for awarding prizes: \( F_{p1} \) and \( F_{p2} \).

The \( F_{p1} \) function is calculated as follows. If, after completing the route, the point falls into a small circle with radius \( R_1 \), all arcs included in the trajectory are awarded a prize equal to 2. If the point falls within the area of the ring defined by the difference \( R_2 \) and \( R_1 \), all arcs that were included in the trajectory are awarded a prize equal to 1. If the point is outside the circle with radius \( R_2 \), the prize is 0.

The \( F_{p2} \) function is calculated as follows. If, after completing the route, the point falls into a dark gray area, all arcs that were included in the trajectory are awarded a prize equal to 2. If, after completing the route, the point falls into a light gray area, all arcs that were included in the trajectory are awarded a prize equal to 1. In other cases, the prize is not awarded to arcs.

The \( F_{p1} \) function sets tougher limits on the prize area than \( F_{p2} \). The \( F_{p2} \) function supports the simple principle of "less is better". In different situations, \( F_{p1} \) and \( F_{p2} \) have their advantages and disadvantages. In general, \( F_{p1} \) provides more opportunities for the organizer of a purposeful movement to manage the process, and \( F_{p2} \) allows for more equitable incentives for participants in the process.

A sample is defined by a set of parameters that define a point in a space of seven dimensions.

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

- \( X_{s1} \) – average prize.
- \( X_{s2} \) – prize for the last implementation.
- \( X_{s3} \) – intensity of arc selection.
- \( X_{s4} \) – average travel time from the start node to the end node.
- \( X_{s5} \) – the time of the last move from the start node to the end node.
- \( X_{s6} \) – the average cost of moving from the start node to the end node.
- \( X_{s7} \) – cost of the last move from the start node to the end node.

Each arc has a similar set of parameters: \( Bi=\{ X_{b1}, X_{b2}, X_{b3}, X_{b4}, X_{b5}, X_{b6}, X_{b7} \} \). The values of the sample parameters are constant, and the values of the arc parameters change over time, characterizing its current state. When making a decision in the node about the direction of travel, the arc for which the distance from \( Bi \) to sample is minimal is selected. In some situations, this decision-making procedure may be modified.

The conceptual and simulation models are described in more detail in [4].

3. Building a simulation model

The simulation model is based on the developed conceptual model. The simulation program (Sim_move) is implemented in JavaScript. An oriented graph of any topology can be set at the input of the Sim_move program. By changing the interpretation of the target parameters and parameters of samples, the program can be used to simulate systems and processes for various purposes.

The route graph is built in three stages.

1. Using technology of geo-information systems, detailed GIS map of the main delays is created. Delays occur at traffic lights, intersections, and pedestrian crossings. Calculating and estimating delays at intersections is a complex task [8]. In our case, the specific value of delay did not matter much. Therefore, observations and expert assessments were used to determine delays.
2. The starting and ending points of the route are selected, and possible paths are determined.
3. Oriented graph of route is construct. In this case, the arc of the graph displays the sequence of sections of the original trajectory. The parameters of the arc (delay time and length) depend on the parameters of the sections that it replaces.

On figure 2 shows the user window of the Sim_move program during the simulation experiment.

![Figure 2. The model window](image)

The left part of the window shows a graph of one of the popular routes in Omsk. Vertex 1 is the initial one. Vertex 21 is the final vertex. The upper middle frame shows the target point, the prize function (two circles), and the points that characterize the route. The middle lower frame contains the simulation results.

- **NUM** – number of route passes.
- **T_m** – average travel time of the route (in minutes).
- **C_m** – the average cost of passing the route (in rubles, fuel costs).
- **Price** – the average prize for completing the route in accordance with the parameters set by the prize function.

The right frame shows the values of the prize function and the parameters of the sample for the model input. In a simulation experiment, some sample parameters may not be taken into account. This is indicated by the "-" symbol.

At any given time, one car moves through the graph. The influence of other cars is simulated by increasing the fixed arc travel time by a random amount of delay. After the car reaches the final node, the next car starts moving in the initial node. The simulation time is set by the number passes of cars over the routes.
4. Results of simulation experiments

When conducting experiments, the conceptual model is supplemented with procedures that take into account the specifics of road traffic.

Before performing the main experiments, the "pioneer" algorithm is run to set the initial data. The essence of the algorithm is that the node selects to move the arc that is least used. This ensures that all possible trajectories from the start node to the end node are used. Thus, for all arcs, the initial parameter values used in subsequent experiments are set.

A "rehabilitation" procedure was used to combat blocking by frequently used arcs of rarely used arcs. If the intensity of use of the selected arc exceeds by 2 times the intensity of use of another arc originating from the node, a low-intensity arc is selected for moving. This gives the rarely used arc a chance to "tweak" its statistics.

For arcs $3 \rightarrow 5$, $8 \rightarrow 15$, $8 \rightarrow 6$ is generated periodically a "traffic jam". The probability that the generated "traffic jam" will be on one of the three arcs is 0.333. The delay time in the "traffic jam" is an input parameter of the model.

The results of the analysis of the influence of sample parameters on the average travel time of the $t_m$ route and the average value prize are shown in table 1.

Table 1. Analysis of the influence of sample parameters.

| Number of experiment | samples       | $T_m$ (мин.) | Price |
|----------------------|---------------|--------------|-------|
| 1                    | {-, -, -, -, -, -} | 46.1         | 1.11  |
| 2                    | {-, -, -, 0, 0, 0}  | 42.3         | 1.23  |
| 3                    | {50, 50, 50, 40, 40, 50, 50} | 41.8         | 1.23  |
| 4                    | {50, -, 50, 40, -, 50, -} | 44.2         | 1.20  |
| 5                    | {-, 50, -, 40, -, 50}   | 41.4         | 1.24  |
| 6                    | {-, -, 50, 40, 40, 50, 50} | 42.1         | 1.28  |
| 7                    | {50,50, 50, -, 50, 50} | 41.7         | 1.22  |
| 8                    | {50,50, 50, 40, 40, -, -} | 41.6         | 1.22  |
| 9                    | {-, 50, 50, 40, -, -, -} | 41.0         | 1.15  |
| 10                   | {-, 50, -, 40, -, -, -} | 41.3         | 1.13  |
| 11                   | {-, 50, -, -, 40, -, -} | 41.7         | 1.24  |

All experiments used the Fp1 prize function with parameters: purpose = {40, 50, 5, 15}. Preliminary experiments were performed to determine the values of the prize function and sample parameters. In each experiment, 5000 route passes were simulated.

The first column shows the number of the experiment. The second column shows the values of the sample parameters. A dash indicates that the parameter was not used in the experiment. The third column shows the average travel time of the route. The fourth column shows the average prize.

The first experiment did not use sample parameters. Changing the trajectory of movement was carried out only the procedure "rehabilitation". In the second experiment, zero values of four sample parameters were used. In the third experiment, all parameters of the sample were used. The results of experiments 1–3 show that taking into account the parameters of the sample when choosing the direction of movement allows you to significantly reduce the $T_m$ and slightly increase the value of prize.

In the fourth experiment, the average values of the sample parameters were used and the current values were not used. In the fifth experiment, the current values of the sample parameters were used and the average values were not used. Comparing the results of experiments 4 and 5, we can conclude that in this case, taking into account the current parameters gives better results than taking into account the average parameters.
Experiments 6-8 show that excluding two parameters from consideration has little effect on $T_m$, but it makes difference which parameters are not taken into account.

Experiment 9 shows a combination of parameters that leads to a minimum $T_m$. Experiments 10 and 11 show an attempt to reduce $T_m$.

The results of the experiments shown in table 1 show that taking certain parameters into account when making decisions can be beneficial, harmful, or not affect anything. There are two reasons for the small difference in results.

1. Different trajectories of motion do not differ much in length and total delay.
2. The "rehabilitation" procedure reduces the value of samples when making decisions being of choosing the direction of travel.

On figure 3 shows the results of fourteen experiments. The consequences of excluding one parameter from the sample and leaving only one parameter in the sample are compared.

![Figure 3](image)

**Figure 3.** The dependence $T_m$ on the composition of sample parameters

All experiments used the parameters of the purpose prize function: $\text{purpose} = \{40, 50, 5, 15\}$. The sample was taken as a basis: $\text{sample} = \{50, 50, 50, 40, 40, 50, 50\}$. Samples with the absence of one parameter were used to obtain $Tm1$. In this case, $XsN$ shows the number of the only parameter absence in the sample.

Samples with only one parameter were used to obtain $Tm2$. In this case, $XsN$ shows the number of the only parameter present in the sample.

The graph shows that the absence of one parameter in the sample has little effect on $T_m$. The absence of six parameters in the sample significantly increases $T_m$. The sample Parameters have different effects on $T_m$.

On figure 4 shows two graphs showing the effect of the $Xp1$ coordinate of the target function point on the value of the prize and the average transfer time for the $Fp1$ and $Fp2$ prize functions.

![Figure 4](image)

**Figure 4.** Effect of the $Xp1$ target point coordinate on the prize and $T_m$
All experiments used sample parameters \( \text{sample} = \{50, 50, -, -, -, -\} \) and parameters of the prize function \( \text{purpose} = \{\text{Xp1}, 50, 5, 15\} \). The left part of the figure shows the dependencies of the average value prize on the Xp1 target point coordinate for the Fp1 and Fp2 prize functions. Naturally, when increasing Xp1, the value prize for the Fp2 function first increases, then remains at the same level (see figure 1). For the Fp1 function, the value prize reaches the maximum values in a certain Xp1 range. The right part of the figure 4 shows the dependencies \( T_m \) on Xp1 for the Fp1 and Fp2 prize functions. For Fp1, the \( T_m \) value has a pronounced minimum. For Fp2, The \( T_m \) value is more stable. Graphs figure 4 show that Fp1 is more suitable than Fp2 for bringing targeted parameters of traffic to a given range.

5. Conclusions
The results of simulation of cars movement allow us to draw the following conclusions.

1. Using samples can serve as one of the decision-making methods when choosing routes for different objects.
2. The choice of parameters for prize functions and samples reflects the interaction between the organizers and participants of the targeted movement and can greatly affect the indicators of achieving goals.
3. There are complex dependencies between sample parameters, goals parameters, and prize functions. Such dependencies can only be investigated experimentally at a level that is useful for practice.

The set of parameters used in the Sim_move program is universal. Therefore, it can be used to analyze systems for various purposes. In the future, we plan to expand the scope of Sim_move.

Acknowledgments
«The work was supported by the program of fundamental scientific researches of the SB RAS № I.5.1., project № 0314-2019-0020»

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