

# Modeling of a Dynamic Interaction of Motor Transport and Natural Systems in Order to Minimize the Risks of Project and Management Decisions

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**Abstract:** Fundamental tasks for the problem of scientific support for the design of transport infrastructure in the ecosystem splits are analyzed. New aspects of simulational application in dynamic interaction of motor transport and natural systems are considered. Method for simulational studies is analyzed. The problems and advantages of the simulation of complex systems are investigated. Mathematical model of the transport infrastructure influence in the environmental situation and A\* search algorithm are developed, which guaranteed to find the shortest path till the heuristic approximation, i.e., it never exceeds the real remaining distance to the target and then this algorithm uses the heuristic in the best possible way: No other algorithm will reveal fewer joints disregarding the joints with the same cost. The successful solution of the problem results from the preliminary theoretical research, partly stated in 20 scientific publications and protected intellectual property objects, including certificates of state registration of computer programs.

**Keywords:** Dynamic Interaction of Motor Transport Systems, Dynamic Interaction of Natural Systems, Minimization, Simulation, Management Decision, Transport Infrastructure, Ecosystems

## Introduction

The growth of human impact on the biosphere, the regional ecosystem, has led to disruption of the natural balance between internal and external factors in the development of civilization and also created new types of risks-economical, ecological, transport and so on (Gunderson and Holling, 2001; Yanitsky, 2000). These kinds of risks may lead to significant damage of insurance companies, increase of morbidity, reduction of average life expectancy, environmental pollution, reduction of species diversity (in flora as well as in fauna), reduction of regional GNP (Bobylev *et al.*, 2008).

The consequences of the chosen solution of building a Transport Infrastructure (TI) become apparent only during the operational phase in the long term perspective.

According to the conflict of interests of parties involved in the coordination of a TI project, it becomes practically impossible to minimize the

negative impact on environment, regional economy, health of individuals; parties often put their signs on the subject of "mutual understanding" rather than compromising their business interests (Gagarina *et al.*, 2012). Solving the problem of inter-branch risks coordination and integrated minimization of them requires an adequate scientific support, in particular modern scientific prediction of the results of any scenario and the response of ecosystems. Evaluation of possible operational errors (Andrews and Bartlett, 2005) at the stage of design of the TI by simulating and choosing the management scenarios with the smallest possible risk is also required.

Development of interdisciplinary scientific methods of identifying the "bottlenecks" requires accounting of static as well as dynamic anthropogenic impacts on the environment (Loucks, 2006; Xu *et al.*, 2006). System dynamics allows to implement static impacts, because they are continuous, constant and do not depend on the place of occurrence. Ecological and

spatial factors must be taken into account (Balmer *et al.*, 2006; Teplova and Gagarina, 2010). Position of the road about the landscape elements (forests, grasslands, lakes, rivers,) is a perfect example of such factor. Because of the above-mentioned factor it is most appropriate to use agent modeling, because it is logical to use animals, inhabiting the given area, as model agents and the landscape-as the environment. Using this kind of approach allows not only to evaluate common ecologic risks, connected to different types of pollution (including noise and vibration pollution), but also to help the conservation of fauna, biodiversity, ecosystem sustainability, taking into account the nature of the natural migration of animals and their specific characteristics. It's also possible to simulate migrations of animals in an around the given medium in the presence of transport infrastructure, that is also depending on the terrain and the spatial arrangement of the elements.

Thus, the problem of scientific support for the design of transport infrastructure in the ecosystem splits into the following fundamental tasks:

- To identify common patterns and methods to reduce environmental risks in the design of transport infrastructure and formalize the problem
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- To develop a methodology for placing environmental and civil engineering (passages for animals), environmental monitoring stations impact on the environment (air pollution, infrasound, accidents,) transport infrastructure

The theoretical bases of the present study are the approaches and methods listed below. Structurally-ecological approach, that consists in determining the permitted corridor (Kavtaradze and Brudnyi, 1987) for the choice of possible technical and economic decisions and comes from the recognition of the primacy of natural systems and public concerns in the design, construction and operation of transportation systems.

### Agent and Imitational Simulation Methods

Using the agent and imitational simulation methods allows to test any project scenarios, working hypothesis on any complex dynamic systems, as well as to study the response of ecosystems while creating a transport infrastructure and to reduce management and project risks significantly.

The advantages of the simulation of complex systems include the following: No need for significant simplification of nonlinear systems; ability to carry out monitoring of the process during a certain period of time; relative simplicity of experiment and observation of different effects compared to their implementation in real conditions; o control the timing of the process being studied (for example, the ability to compress the time scale); possibility of an unlimited number of experiments with different parameters; possibility of application in a wide range of areas; the ability to use the selected strategies in the practice of designing and operating the highways. The general structure of the model can be represented as:

$$E = F(x_i, y_i)$$

Where:

$E$  = The result of the system activity

$x_i$  = Are controlled variables parameters

$y_i$  = Are uncontrolled variables and parameters

$F$  = The functional relationship between the  $x_i$  and  $y_i$ , defining the  $E$  value

The implementation of the project includes the following steps (Ye and Alexander, 2013; Mordovin, 2012):

- Development of a conceptual model
- Preparation of an input data model
- Choice of modeling tools
- Development of the software model
- Validation and adjustment of the model
- Planning the computer experiments
- The modeling
- Analysis of the simulation results
- Interpretation of the results
- Approbation of the recommendations in the highways designing highways management

According to the data, presented in Table 1, the system dynamics was chosen for modeling.

Basing on the studies of characteristics of modern simulation environments (Balmer *et al.*, 2006) it is possible to distinguish the most common of them (Table 2).

After carrying out the analysis AnyLogic was chosen for the implementation of our project. The main stages of work were established after the interdisciplinary research plan specification.

Theoretical studies of the principles of evaluating the impact of transport infrastructure on the environment, roadside ecosystem.

Table 1. Comparative characteristic of simulation techniques

Characteristics	Name of the method		
	Discrete-event simulation	Agent-based modeling	System dynamics
Object	System	decentralized agent	A complex system`
Subject	The system behavior, using chronological sequence of events	The behavior of the agent and its effect on the behavior of the whole system	The dynamic behavior of a complex system, depending on its structure
The direction of modeling	Decomposing	Composing	Decomposing
Abstraction level	Low, medium	Low, medium, high	High
Discreteness of the method	Discrete	Discrete	Continuous
Area of usage	Manufacturing processes, logistics, business processes, health care	Manufacturing processes, logistics, business processes, consumers' market	Business processes, objects development, population dynamics
Time of occurrence Founder	1960 s Jeffrey Gordon	1990 s -	1970 s J. Forrester

Table 2. Comparative characteristics of simulation environments

Characteristics	Arena	ExtendSim	AnyLogic	AutoMod	ProModel
Year of appearance	1998	1988	1999	1999	1999
Developer	Rockwell automation, Inc.	Imagine That, Inc.	XJ Technologies	Applied materials Inc.	ProModel corporation
Specific language	-	ModL	Java	Inbuilt	Inbuilt
Documentation	+	+	+	+	+
Discrete-event simulation support	+	+	+	+	+
Agent modeling support	-	+	+	-	-
System dynamics support	-	-	+	-	-
Possibility of using a combined approach	-	+	+	-	-
Users interface development	-	-	+	-	-

Development of a mathematical model of the transport infrastructure influence on the environmental situation. Development of a simulation model for the interaction of the transport infrastructure with the environmental situation. Development of a software tool for simulating the transport infrastructure impact on the changing environmental conditions, including the changes of animals migrations in the simulated landscape. Development of an algorithm of quantitative evaluation of technical and environmental risks created by the transport infrastructure (air emissions, noise, infrasound, accidents). Development of a methodology for placing environmental engineering devices (for example, special passages for migrating animals), stations for monitoring the effects of transport infrastructure impacting the regional ecosystem. Creating modeling tools of managing techniques and methods of minimizing the environmental damage during laying of tracks.

The current situation in the field of transport and environmental problems research requires the development of theoretical principles of interfacing the transport systems with regional ecosystems. (Kavtaradze, 1997) The presence of high-level

economic, environmental and transportation risks appearing during the design, construction and operation of transport infrastructure, such as highways, is the result of the following factors:

- Presence of a complex system of direct links and feedbacks between an ecosystem and a road
- Impossibility of the field experiments
- Short time and low budget of the research
- Lack of management tools able to minimize the overall risk of inter-branch interests conflict

Nowadays there is an intensive worldwide ongoing development of “sustainability indexes” that would be able to display the state of environment in terms, suitable for practical work, characterize the admissibility of increasing the industrial and transport burden on the environment. Development of a system of indicators for design, construction and operation of roads, which do not exceed the socially acceptable risks, it is a complex scientific task, which requires joint efforts of experts of road and transport industries, environmental protection and others. The most promising results were obtained in the laboratory

of Ecology and Conservancy of the Faculty of Biology of the Moscow State University, led by Professor Kavtaradze (Yolcu *et al.*, 2014).

However, so far only a scheme of solving the problem is offered. In order to build a complex analysis methodology and model of evaluating the impact of transport infrastructure on the environmental situation both static and dynamic effects on the environment must be taken into account. According to the amount of data, being analyzed by the team during the preparation for the work on the subject, it turned out that the proposed approach does not have any analogues in Russia or abroad; it is based on the mathematical dynamic system modeling of evaluation process and achieving the lowest environmental, economic, insurance and social risks.

The successful solution of the problem results from the preliminary theoretical research, partly stated in 20 scientific publications and protected intellectual property objects, including certificates of state registration of computer programs № 2012615015 “the operational control of distributed load logistics systems software tool”, № 2009612669 “software for designing networks for environmental monitoring stations in towns and cities”; № 2012611462 “decision-making support program for the management of complex communications patterns”.

## Implementation and Realization of Operation Model

For the phased implementation of the previously proposed schemes (Greene, 2012; Mordovin and Kavtaradze, 2012; Teplova, 2009; Bhat and Singh, 2000) of direct links and feedbacks between the ecosystem and the highway it is necessary to submit the IT project in the shape of a formalized interaction between the internal elements of the model.

The following parameters of the model should be considered:

Characteristics of two animal species:

- Population dynamics
- Population size
- Existing types of natural and artificial landscape (forests, fields, lakes, rivers, cities)
- Preferred habitats (landscape type, area and “depth” of the ecosystem (conditional diameter))
- Migration areas (for each landscape type, area and form of the ecosystem, the quantity of migrations)

- Average speed/duration of road-crossing
- Characteristics of the nodal points of pathways crossings

Characteristics of the designed highway:

- Construction cost of 1 sq. km. of the road (the integral area ratio and length of road pavement is conditionally accepted)
- Number of lanes
- Lane width
- Calculated intensity of the road traffic

The interaction of the highway and animals happens through the environment-landscape and the ecosystem for the operation of the model can be described by the following elements: Agents  $A = \{A_1, A_2, A_3, \dots, A_n\}$ -a set of agents; links  $L = \{L_1, L_2, L_3, \dots, L_n\}$ -a set of links between agents and environment. In this particular case there is only 1 environment; environment  $E$ -the area, where the highway is designed and built, agent function and impacts are defined (internal as well as external); agents properties  $A_i = \{P_1, P_2, P_3, \dots, P_m\}$ -a set of static, dynamic, common and individual characteristics (current location, condition, habitats, migration ways and nodal points and so on) of every agent, that can change during the process of model work.

Forms of interaction  $L_j = \{I_1, I_2, I_3, \dots, I_m\}$  – a set of possible actions of agents. After every iteration of work of the model a new condition  $A_i, new = f(A_i, E, L_i)$  for each agent is calculated. Habitats, migration paths and intersection nodes of migration paths are created randomly, but taking into account already occupied areas (Fig. 1) and ecology of animals (wild boar, elk). All the points must be connected by paths. In order to reduce the abstractness of network paths, we note the basic principles of building the model: (1) The nodal points have to be connected in a ring (i.e., migration occurs within the same natural landscape), points of visiting and dwelling must be connected to the nearest nodal point (taking into account the ecology of migrating species and landscape features).

The landscape is always heterogeneous and ecosystems are different, due to this fact extra effort to formalize the migration patterns of animals is required. The shortest way of migration is not always possible. The algorithm of  $A^*$  search with partly modified function of estimating “the energy cost” of the way of solution is used to build the paths between joints.

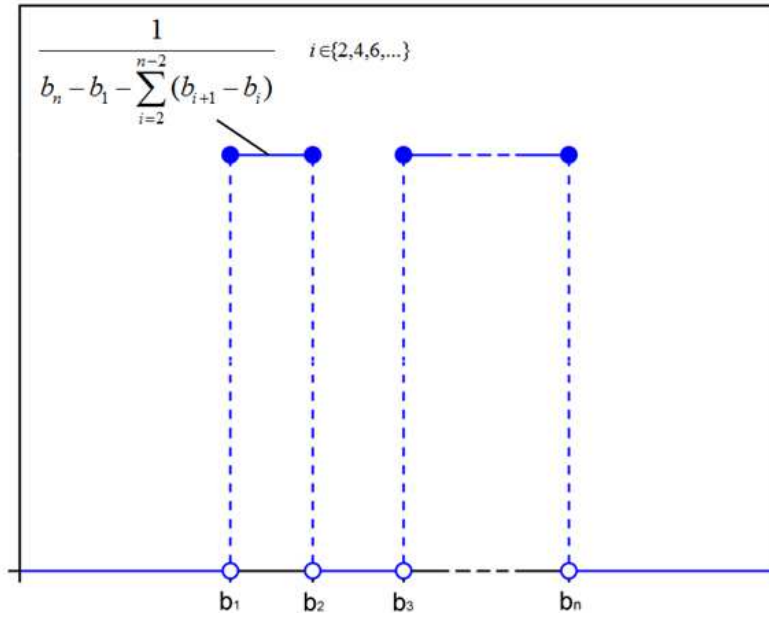


Fig. 1. The probability density distribution

In this heuristic search all joints are sorted approximating the best route which goes through this particular joint. A typical formula of heuristics is as follows:

$$f(n) = g(n) + h(n)$$

where,  $f(n)$  is the value assessment, attributed to joint  $n$ ,  $g(n)$  is the lowest cost of arrival at joint  $n$  from the starting point  $h(n)$ , a heuristic approach of the path cost to the target from joint  $n$ .

Thus this algorithm combines the previous path length registration with heuristics. As some joints might be processed the second time (in order to find the optimal paths) a new list closed must be added later to detect them. The A\* search algorithm is guaranteed to find the shortest path till the heuristic approximation  $h(n)$  is admissible, i.e., it never exceeds the real remaining distance to the target. This algorithm uses the heuristic in the best possible way: No other algorithm will reveal fewer joints disregarding the joints with the same cost. The Fig. 2 and 3 illustrates the way the algorithm of A\* search copes with the problematic situations.

In practice the algorithm of A\* search turns about to be very flexible. In our case the state of the model is a cell or a position occupied by the object, but if necessary the state of the model can be represented by orientation and velocity (e.g., when searching the route for a tank or any other vehicle-their turning radius is getting worse in case of a high velocity).

Nevertheless while modeling the behaviour of animals the “lack of logic” of their behaviour is admitted: Let’s recall an ordinary example-a hare runs away winding.

The neighboring states of the model can change depending on the local situation. The adjacent positions can be excluded as they are impassable. Some types of locality are impassable for particular objects, but they are passable for other ones-for objects which “turn around” slowly, cannot move to any adjacent cell.

The energy cost of the transfer from one position to another can be presented by many parameters: An ordinary distance between positions; transportation costs due to time or fuel needed for relocation, fines due to crossing the objectionable area; bonuses for crossing the preferable areas; as well as aesthetical considerations (e.g., in case when the cost of diagonal relocations is the same as of orthogonal ones it is better to increase their cost so as to make the routes appear more direct and natural).

The approximation usually equals the minimal distance between the current joint and the target multiplied by the minimal cost of relocation between the joints. This ensures the heuristic  $h(n)$  admissibility.

The target isn’t necessarily the one accepted position; it can consist of several positions. In this case the approximation is to be equal to the minimum of approximations to all possible targets. The cost of the path limitations or the distance limitations or the both can be easily performed.

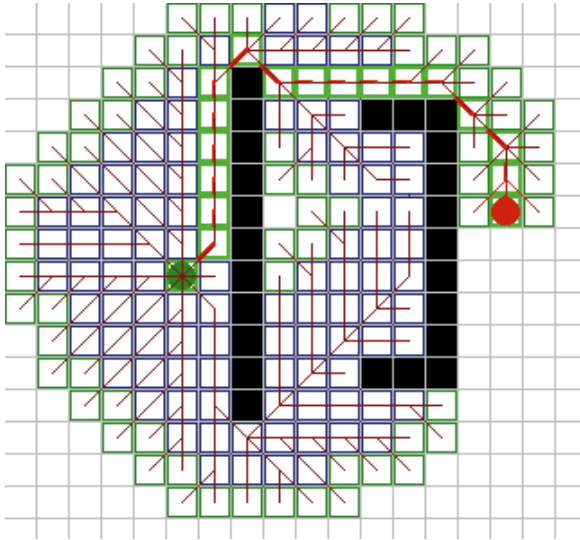


Fig. 2. A particular case of the A\* search algorithm performance

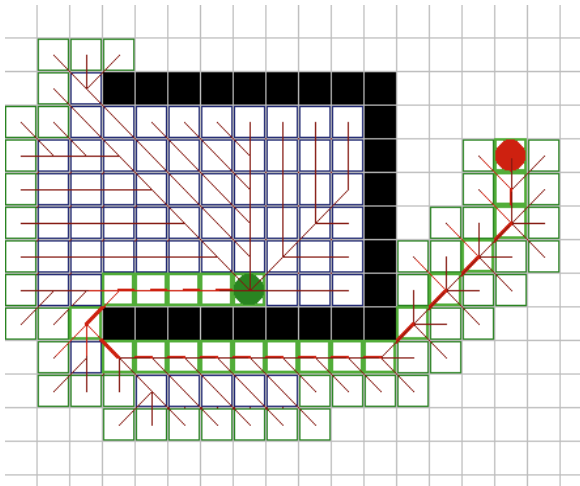


Fig. 3. A particular case of the A\* search algorithm performance

## Conclusion

There exist some situations in which the A\* search algorithm doesn't work: Requirements of real time performance, memory and processor time limitations hamper the algorithm functioning. Thus a large scale of a map can demand hundreds of cells in lists Open and Closed, which require a huge memory. Even if the memory is sufficient the algorithms of work with these lists can prove to be ineffective.

The algorithm functioning quality greatly depends on the heuristic  $h(n)$  approximation quality. If  $h$  is close to the true cost of the remaining way, then the performance will be very high and on the other hand, poor values of  $h$  affect negatively the performance.

The further work on the project supposes the realization of the main functional of the simulation model and adaptive interface, as well as the launch of a test version of the program. In order to do it the following algorithms will be developed:

- The landscape digitization algorithm, 3d in perspective
- The algorithm for constructing the most probable animals relocations based on generalized field surveys
- The algorithm of animals relocation in the presence of highways
- The effectiveness of ecological-engineering constructions at highways

In future the wide application of the results obtained is supposed when constructing objects of transport infrastructure.

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## Author's Contributions

All authors equally contributed in this work.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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