OPTIMISATION OF ROUTE-PLANNING UNDER INDEFINITE RISK CONDITIONS

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Abstract: *This paper describes an algorithm of data transformation with a view to provide support for the decision maker. The aim of the paper is to develop a multi-purpose algorithm of building sets of optimal routes, taking into consideration most of the real factors that provoke risks. A simple and effective method of multicriteria optimization was proposed and developed.*

Keywords: *emergency situations, microsituations, road conditions, weather conditions, objects of high danger, multicriteria optimisation.*

ACM Classification Keywords: *H.1 Models and Principles – General*

Introduction

Nowadays vehicle route management in indefinite emergency situations uprising tends to be even more important. This problem includes modeling of transportations, decision-making optimization, and development of informational environment for decision-making support in field of high caution cargo transportation. The most of these problems is still solved by people, using their experience and intuition. Unfortunately, human mistakes take place and can dramatically influence the situation, especially in case of high caution cargo transportation.

Human factor is one of the most important and destructive risk-producing ones. Humans are strongly influenced by their emotions, their health state, their mood and other things, that actually, should not affect decision-making. That’s why decision-making should be supported by mathematical models and methods that negate these problems as widely as possible.

Organization of safe routes for high caution cargo in case of emerging of an exceptional situation is one of the most important problems of traffic management, which requires updating and upgrading of approaches and decision methods used for this problem and usage of newest inventions in information technology.

The most frequently used method is still single-criteria optimization. Usually time or distance is optimized in order to meet client requirements. These methods do not need any information, concerning weather or road state or any other very important factors. So these methods simply ignore the most risk-emerging events. Of course this leads to great risks and therefore losses.

One-criteria optimization do not deal with risk, that is its major and fatal disadvantage. Modern transport can already provide speed and cheapness, but it is still not protected from risk.

Route management now needs a simple and effective tool for risk optimization. From single-criteria optimization we move to multi-criteria optimization, which is the key to accurate and effective way to avoid major risks, summoned by weather, catastrophes and other negative events.

The goal of this work is to provide the tool, which would possess the following features: computational optimality, educability, high adaptability, human factor taken into consideration, both changeable and unchangeable factors taken into consideration, ability to process data of different types.

We have developed this tool, it is easily adaptable for any kind of transport network. This work widely uses a term of "micrositaution", which means a set of qualitative and quantative rates (which are characteristics of a micrositaution) and a territory or a part of road, on which these rates can be considered as constant. Any change of parameters generates a new micrositaution. So, they can evolve into each other under influence of some momentary events or conditions. These evolutions can be reduced to scenarios, because mainly, similar micrositautions under similar conditions evolve into similar new micrositautions.

Any road between two cities can be presented as a chain of different micrositautions. Each micrositaution carries its own risk. We have developed a way of aggregating these micrositautions into one complex rate, basing on which it is possible to perform optimization.

We shall show the principle of our development on a simple problem.

The essence of work

The proposed method:

A system is presented in a form of an oriented graph, imitating a traffic network, a vehicle, moving in this network, weather conditions, emergency situations and objects of high danger. Set of possible decisions contains all possible edges. A set of scenarios S consists of all possible finite sets of sequential micrositautions, where the starting micrositaution is the current situation, surrounding the vehicle. We introduce a set of extreme situations and three metrics, which will be described a bit later. The most important point here is, that we use metrical distance between the examined micrositaution and the extreme set to optimize risk. In some sense, norm, derived from all of three metrics is a kind of risk-measure. An extreme micrositaution is such a situation, which has its risk level higher than allowed. [Кузёмин 2006].

Every micrositaution x has a corresponding finite fuzzy set of micrositautions, which gives a finite number of possible system development scenarios. A decision is a chain of fuzzy sets of micrositautions. To simplify, we suppose, that we can fold a fuzzy set into one non-fuzzy micrositation, using their belong function. So, than, decision is a microsituational chain.

So, the problem looks like:

$$ch^* = arg\left(\min_{ch \in CH} \int_{x \in ch} |x| \right),$$

where CH is a set of all allowed chains.

Scenarios and transition probabilities can be defined either by an expert estimate, or using statistical data about early routes and microsituational sequences.

Weight vector is built using educational algorithms. Constraints are set by expert estimates.

Now we identify criterion, used by decision-maker, while searching for optimal decision. We have three main criterion: extreme situation (of natural or technical origin) risk, traffic accident risk (involving our vehicle only), robbery/stealing risk. All three criterion depend on system parameters and can be computed for every microsituation, and respectively for every decision. In addition to system parameters we use a priori probabilities of all three risk types in form of either statistical estimates or interval estimates. [Кузёмин 2007]

Now we shall clarify criterion vector more thoroughly. Let f_A, f_E, f_R be criterion functions for an accident, an extreme situation and a robbery. A priori probabilities are Q_A, Q_E, Q_R respectively. Vector of weather variables $\overline{Wt}$, a cumulative visit coefficient K_R, time t, passed distance s. In addition we introduce an extreme situation object. This type of object is a bounded area, in which it affects microsituation parameters accorfing to the expert-defined function depending on object's special parameters and microsituation parameters. Let it be E.

Here we have defined all the factors, which form preference relation for decision set in every microsituation.

Every microsituation carries a set of parameters, significancy of which depends on a certain scenario. Here they are: roadbed quality, road profile complexity, presence of high danger objects, astronomical time, weather conditions, surrounding relieve, crime rate, traffic load, visibility, roadbed state. [Hamdy 2007] These parameters are variously connected with each other and are used for computing criterion values.

Being in microsituation x we solve the following problem:

$$c\ \hbar = \arg\left(\min_{\mathrm{ch} \in \mathrm{CH}} \int_{\mathrm{x} \in \mathrm{ch}} \alpha_A f_A^r \left(\overline{\beta_A} \times \left(Q_A, E, t, s, \overline{Wt} \right) \right) + \alpha_E f_E^r \left(\overline{\beta_E} \times \left(\overline{Wt}, E, Q_E \right) \right) + \alpha_R f_R^r \left(\overline{\beta_R} \times \left(Q_R, K_R \right) \right) \right),$$

where CH is a set of chains, beginning in x. Here $\overline{\beta_A}, \overline{\beta_E}, \overline{\beta_R}$ - factor weight vectors.

After decomposing factors down to parameters we obtain the following problem:

$$ch^* = \arg\left(\min_{ch \in CH} \int_{x \in ch} \overline{\alpha}(f_A^r\left(\overline{\beta_A} \times \left(Q_A, E, OHD, t, s, \overline{Wt}, Rc, Rq\right)\right),\right.$$
$$\left., f_E^r\left(\overline{\beta_E} \times \left(\overline{Wt}, E, Q_E, OHD\right)\right), f_R^r\left(\overline{\beta_R} \times \left(Q_R, H, CR\right)\right)\right)$$

Here Rc, Rq - road profile complexity and roadbed quality respectively. OHD – objects of high danger, H – pass history, CR – crime rate.

Now, let's introduce metrics, that we will use during optimization.

Low-level metrics is a simple weighted Euclidean metrics of order 2, for the set of vectors $\left(Rc, Rq, OHD, H, CR, Q_A, Q_E, Q_R\right)$ with weight vector α_L.

Middle-level metrics is a weighted Euclidean metrics of order 2, for the set of vectors

$\left(Rc, Rq, OHD, H, CR, Q_A, Q_E, Q_R, \overline{Wt}, K_R, E\right)$ with weight vector α_M.

High-level metrics is defined using norm

$$|x| = \overline{\alpha}(f_A^r\left(\overline{\beta_A} \times \left(Q_A, E, OHD, t, s, \overline{Wt}, Rc, Rq\right)\right), f_E^r\left(\overline{\beta_E} \times \left(\overline{Wt}, E, Q_E, OHD\right)\right), f_R^r\left(\overline{\beta_R} \times \left(Q_R, H, CR\right)\right)$$

Optimization Algorithm:

1. Defining the set of decisions.
2. Defining the extreme set.
3. For each decision we obtain a low-level distance between its results and extreme set.
4. Decisions, which are too close to the extreme set are dropped.
5. Using middle-level metrics we drop some more decisions.
6. Using norm, derived from middle-level metrics, we obtain speed limit for each of the microsituations.
7. Using speed limit we simulate vehicle movement and microsituations' evolution and compute distance, passed by the vehicle in each decision.
8. Decisions, which do not meet the constraints, imposed on daily distance and schedule, are discarded.

9. Using time, driver’s state, speed limit and first-level risk function we obtain high-level distance between decision and extreme set and high-level norm for each of the microsituations.

10. Using high-level norm we obtain an integral estimate for the risk.

11. We choose decision, which has the lower high-level norm within given set.

Sphere of application:

1. Informational intellectual systems for emergency situation control. Carriers will be able to change their route in case of emergency immediately, not waiting for the traffic controller order. If any of current expeditions faces an extreme situation, the route changes can be applied to all following expeditions, wherever that expeditions are at the moment. This will reduce the risk of more than one expedition encountering extreme situation.

2. Notification systems. Having a big enough database of emergency situations and simply route-passes will allow to forecast situation development for definite time horizon. After reaching some size the database will allow to minimize risks at the stage of their uprising. The model will gain ability to take into consideration periodic weather changes, seasonal winds, snow melting and so on.

3. Traffic scheduling systems. In case an expedition consists of more than one vehicle, we will be able to diversify risks by using different routes for different parts of one expedition. This will increase the possibility of successful delivery. Moreover, it will make the database reach forecast-size even faster.

4. A single unified route-pass-database. Emergency situation processing method will lead to a database, which will be able to be used for commercial applications and platforms. Development of a common emergency and route-pass description protocol will improve personnel management and vehicle management beginning from vacation scheduling and crew planning and ending with scheduling inspections and vehicle choice for any specific run.

5. Personnel education and support in case of emergency. Using an automated decision-making system will decrease human mistake probability. Any human-specific mistakes will be avoided and risks therefore decreased.

Municipal departments will use obtained information for preventive measures planning in regions of high-level risk. This also will help road building planning. Road creation and modification with a view to a priori emergency risk will make roads even safer.

Emergency department will get an effective instrument of rescue operations planning and their own infrastructure impact.

Scientific novelty:

Usage of multicreteria optimization instead of one-criterion and muti-stage optimization. While estimating risk levels different factors and characteristics of microsituations are taken into consideration, for example: roadbed quality, road profile complexity, visibility, astronomical time, weather conditions and so on. Optimization is performed in three stages to decrease computational charge. Model of estimation and algorithm of optimization are developed as sets of connected separate blocks; each of them has an ability to be educated and modified. Estimation method can also be obtained from gathering and processing expert estimations. The model can be clarified and completed with any amount of blocks, built within the same principle. Any block can be independently modified in case decision-maker’s preferences change. Using simulation in target function computing: for more adequate results we simulate expedition movement using speed limit modified by risk level and human fatigue. After that we perform additional optimization with simulation results taken into consideration.

Practical value: The developed method can be widely spread, in cargo, cash and passenger transportation with some transportation type adjustment. The model allows changing route and minimizing risks in immediate real time. Carrier will decrease insurance charges, use its human and technical resources more efficiently. A similar model can be embedded as a social service. This service will notify about any non-standard situations on the current route and suppose alternative actions in real time. Combined with GPS-navigation this service will help avoiding overloads of certain road sectors, kilometer-long traffic jams behind traffic accidents on highways, it will help rescuers to react immediately. Every driver and every car will act as a sensor, transmitting data about surrounding microsituation. Resection of emergency situations’ effects will be speeded up due to decrease of traffic. Finally, if this model is widely embedded, having enough computational capacity, it will principally change methods of route-planning.

Figure 1 shows examples of testing the algorithm on a simple network with edges of close length and characteristics. This was done so to illustrate ability to avoid extreme situations by the algorithm.

Conclusion

In this work we have created and developed a method of multicriteria optimization route planning. The main advantage of the method is it’s high adaptability, educational ability and low computational charges. It overbears methods of one-criterion optimization due to the fact that it allows both minimizing risks and optimization not only by distance, but also by time. We have developed the described algorithm using Wolfram Mathematica for Students. The model successfully performed on simple networks with randomly generated disturbances (extreme situations) of unified structure.

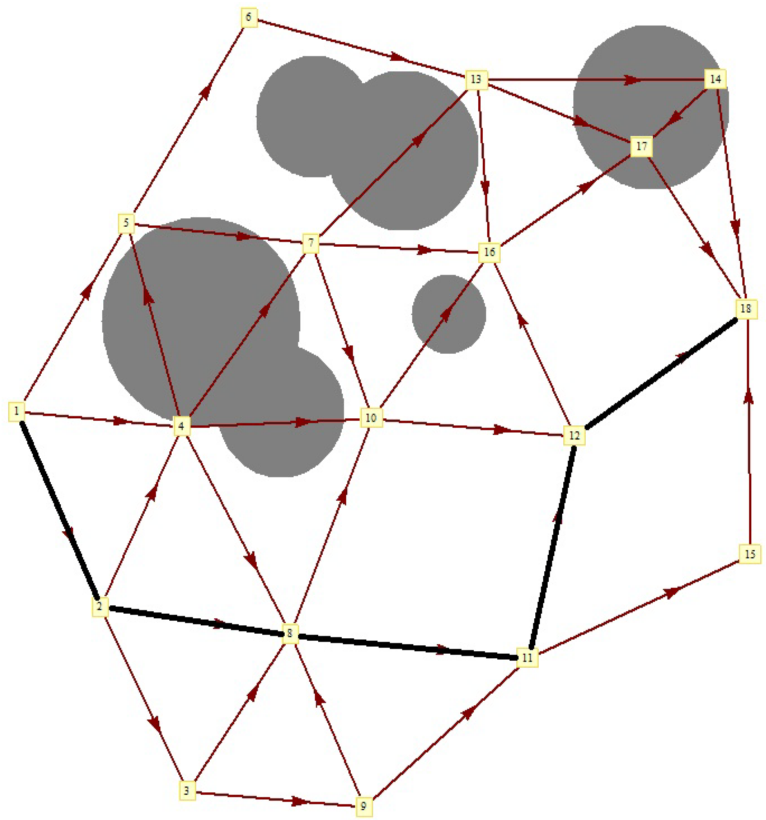

Figure 1 Example of a Test Map - randomly generated extreme situations with solution track.

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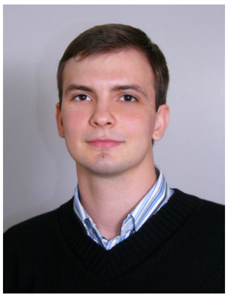

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