Simulation of dangerous substances outflows into the environment because of traffic accidents by dangerous substances transport.

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Abstract

In this article there are presented new procedures and methods applied to calculation of environment exposure by dangerous substances outflows in road transport.

Key words

Ecological risks, dangerous substance, exposure, probit function, bandwidth

1 Introduction

Since 2008 there is solved the project BIOTRA in the Czech Republic, which is covered by National research program. The project is aimed for methodology creation of ecological risks evaluation associated with dangerous objects transport in special view of environment biotic elements.

2 Transport risk assessment

Standard methodic of present and planned traffic way effect evaluation to the environment is oriented to exhalation, dustiness and noise assessment by common traffic. The part of road transportation risk analysis is also the possibility of a vehicle accident connected with dangerous substance outflow. The probability of a major accident is low but the consequences may be large. At present, there is no methodology, which may allow complex road transport risk assessment in light of dangerous substance potential outflow consequences for the environment.

The risk analysis represents complicated process even if the algorithms for exposure and population jeopardy modeling in consequence of fire, explosion or toxicity can be found in technical literature. The trait of such problem is individual and social risk assessment in potentially affected area. The risk is possible to quantify and for its acceptability decision making is this quantification even necessary. Quantitative assessment represents an exposure. It is a numeric value (e.g. estimated number of deaths caused by an event per year) or numeric function, which describes the relation between probability and consequences of existing hazard. The hazards may be machines, activities or technologies, but also different objects or processes which endanger humans or environment. Generally the risk is the product of dangerous event probability and its consequences.

3 Potential dangerous substance outflow

The significant danger for transport, human health and environment is the dangerous substance transport. By traffic accident there are some following characteristics:

- The substance quantity is limited by transport vessel capacity (road tank, tank car),
- the escape time is limited by the vessel discharge; it is assumed the worst case, which is the instantaneous outflow of whole tank volume to the environment,
- the outflow location is not known in advance, it may be situated wherever on the transport route.

4 Outflow calculation and display from stationary sources

The dispersion models result (air-borne spread, fire, explosion, spilling) is time variable concentration field of escaped substance. Generally it is calculated several concentration fields for chosen conditions combinations. Concentration field and substance dangerousness parameters are inputs for respondent answer models to negative impact. Negative impact (toxicity, thermal radiation, shock wave, radioactive radiation) is necessary to quantify. It happens by the help of exposure dose calculation, which represent physical, chemical and biological effects depending on substance concentration and action time.

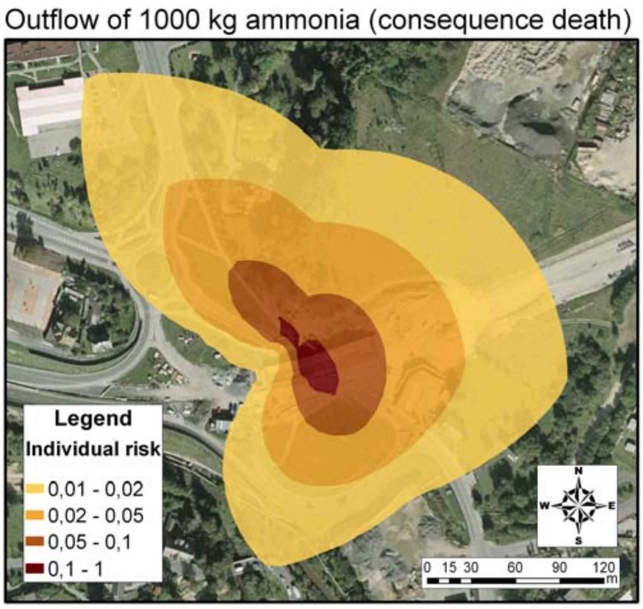

Figure 1: Example of human death probability by toxic exposure in dependence on source distance (instantaneous outflow 1000 kg NH3, Town - Liberec)

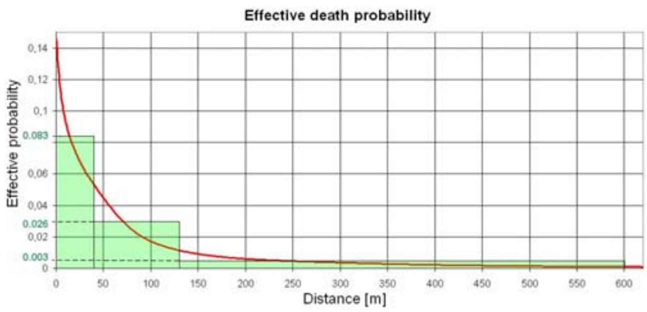

Figure 2: Effective death probability depending on the distance from the source

Tab. 2: Polygon parameters

Interval Index *j*	Probability interval [%]	Distance r_j [m]	Average probability in the interval P_i [%]
1	>5	40	8,3
2	5 - 1	130	2,6
3	1 - 0,1	600	0,3

According to need it is available to divide an effective probability to more intervals and so reduce the error, resulting from divergences between probability vector and average values between intervals. Then the unit social risk is the sum of risks in determined partial areas.

Unit social risk

$$SR_j = \sum \left(IR_j \cdot \sum \left(H_i \cdot h_i \right) \right)$$

Where IR_j is unit individual risk in *j*-partial area,

H_i number of people *i*-category in *j*-area,

h_i people protection level coefficient i-category

Unit social risk

$$SR_j = 0{,}136 \cdot \left(0{,}083 \cdot H_1 + 0{,}026 \cdot H_2 + 0{,}0034 \cdot H_3 \right)$$

5 Bandwidth exposure for liquids

The reach bandwidth assessment of negative effects for liquids is more difficult than for gases. After the liquid flows out to the soil, three different processes with different intensity will begin: diffluence, imbitition, vaporization. These processes are necessary to simulate simultaneously, because the imbitition and vaporization depends on the surface of created pool whereas the diffluence is affected by decrease of liquid, which soaked into or evaporated.

Diffluence depends especially on liquid parameters, grade and surface quality. Generally the width and the depth of a pool sink when the grade grows. But the depth depends on surface type considerably. The typical depth on the relatively smooth surface (asphalt, concrete) is in millimeters. Vegetation greatly increases the surface of possible handhold and it creates roughness, where some part of liquid stays. Even bigger effect the unevenness can evoke (field striae). The imbitition is conditional on permeability and porosity of seat rock. The vaporization is conditional on liquid parameters and environment temperature.

For reasons given it is clear, that the solution includes two basic types of problems:

- Physical problems evaluation,
- finding of necessary area characteristics.

For exposure bandwidth determination it is most important diffluence. Another processes decrease the liquid range, because the progressive amount of the liquid decreases in time. The amount decreases also due to liquid handhold on the land surface. Maximal spread distance from the route will be reached on the level surface, which is practically asphalt or concrete. The range of the liquid will depend on the grade and liquid parameters.

The size of incurred pool area is possible to evaluate according to following formula [10]:

$$A = \frac{Q}{h \cdot \rho} \text{ or } A = \frac{V}{h}$$

Where A *is* spilled liquid area [m^2],

V pool liquid volume [m^3],

Q total liquid amount in pool [kg],

ρ liquid density [kg·m^{-3}],

h spilled liquid pool depth [m].

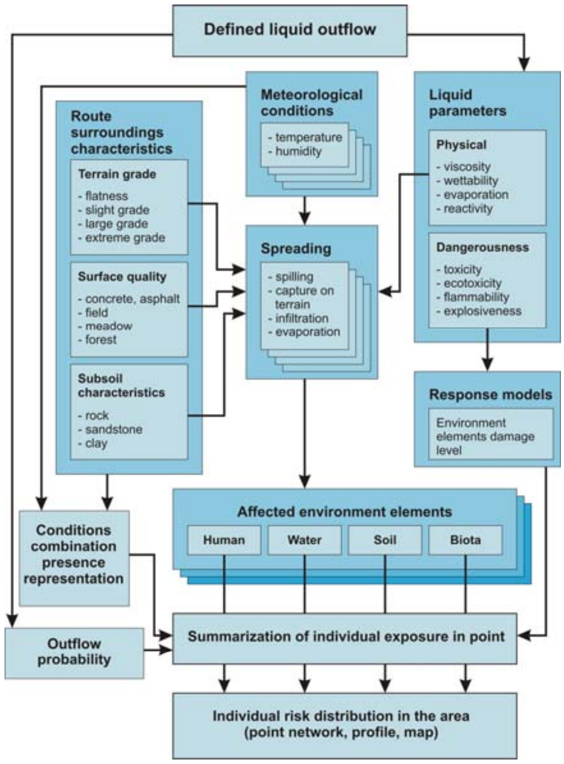

Figure 3: Individual risk evaluation for liquid defined outflow from stationary source

The pool depth is a liquid column high, which matches to its amount, placed on the surface unit area. It is dependent first on terrain roughness and cover quality.

In the first approximation we suppose, that the pool on the sloping surface will be elliptical with the source in focus. In 2008 it was proposed some formulas for ellipse half axle length calculation and also for liquid range on the terrain. These formulas were modified in 2009 and are mentioned in next text.

Major axis length increases with the grade and with decreasing liquid viscosity. When the terrain grade increases, then the liquid depth decreases, because the terrain roughness is not quite filled with the liquid.

Spilled pool area in the form of ellipse is formulated like:

$$A = \frac{V}{h \cdot \cos \varphi} = \frac{\pi \cdot a \cdot b}{h \cdot \cos \varphi}$$

Where a is major ellipse axis of liquid pool [m],

b secondary ellipse axis of liquid pool[m],

φ terrain slope angle [-].

For half axes it is a system of 2 equations:

$$a = \frac{V}{\pi \cdot b \cdot h_{\max} \cdot \cos\varphi} \quad ; \quad \frac{b}{a} = e^{-\frac{\sin\varphi}{\mu \cdot c}} \cdot \cos\varphi$$

Where $h_{\max}$ is spilled liquid pool depth on level surface [m],

φ area slope angle [-],

μ liquid dynamic viscosity [N·s·m^{-2}],

c terrain handhold factor [m^2·s^{-1}·N^{-1}].

After the solution we get half axes:

$$a^2 = \frac{V \cdot e^{\frac{\sin\varphi}{\mu \cdot c}}}{\pi \cdot h_{\max} \cdot \cos\varphi} \qquad \frac{b}{a} = e^{-\frac{\sin\varphi}{\mu \cdot c}} \cdot \cos\varphi$$

and eccentricity:

$$E^2 = \frac{V}{\pi \cdot h_{\max} \cdot \cos\varphi}\left(e^{\frac{\sin\varphi}{\mu \cdot c}} - e^{-\frac{\sin\varphi}{\mu \cdot c}} \cdot \cos^2\varphi\right)$$

Then it is available to determine the liquid flow distance L :

$$L = E + a = \sqrt{\frac{V}{\pi \cdot h_{\max} \cdot \cos\varphi}}\left(\sqrt{e^{\frac{\sin\varphi}{\mu \cdot c}} - \cos^2\varphi \cdot e^{-\frac{\sin\varphi}{\mu \cdot c}}} + \cos\varphi\sqrt{e^{\frac{\sin\varphi}{\mu \cdot c}}}\right)$$

6 Liquid outflow simulation in digital terrain

It is ideal to use the relief 3D raster model analysis. It works with space data transformed to the geographic coordinates.

The data result from Czech Republic base map digitizing. Reference ratio scale is 1:10 000. Data model is in vector format.

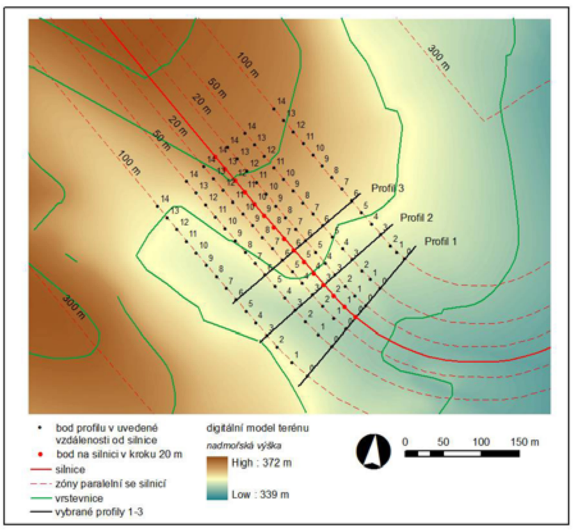

Figure 4: The road with defined point network for generalized off-road tread determination

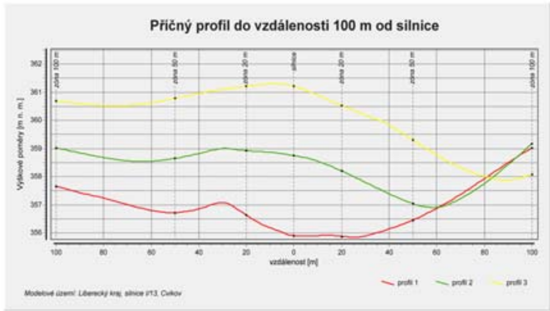

Figure 5: Cross profile to 100 m distance from the road, real generated from DMR GRID

On figure 6 there is pictured off-road tread with brown color, whereas the point X is the outflow source. Off-road tread is characterized with n points on the right a left side of the road (on figure there is only one direction). Horizontal distances of single points from the source are named as a_i, elevations above sea-level as h_i. The green color have inclination lines for each point, from which it is available to determine degree of incline φ_i.

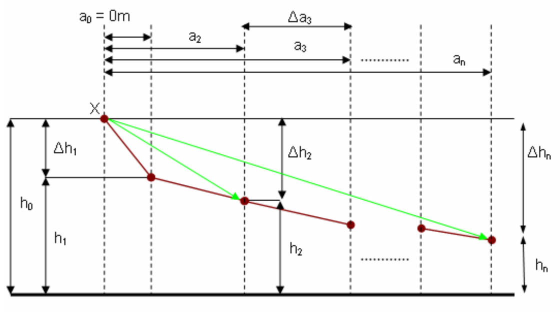

Figure 6: Symbols for terrain grade evaluation

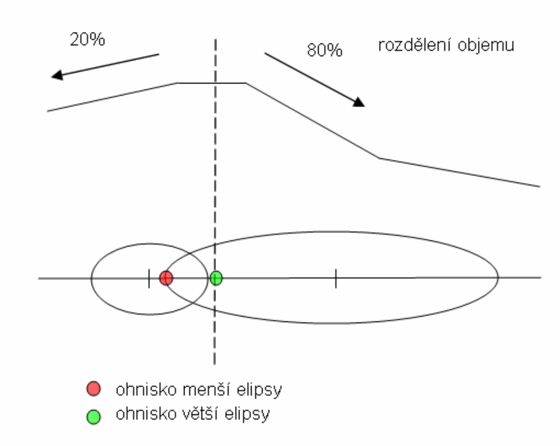

Figure 7: Volume partition schema and elliptical pools location by inclination to both sides from the road.

Model principle

Liquid spread process is spatially discretized by the help of square network. Time discretization is realized with the time steps calculation. The cut of interest area is in the model divided into square elements by the help of square network. The surface of each element is horizontal, homogenous in term of all its parameters and it presents location whereon the processes are time steps simulated and the liquid balance is done.

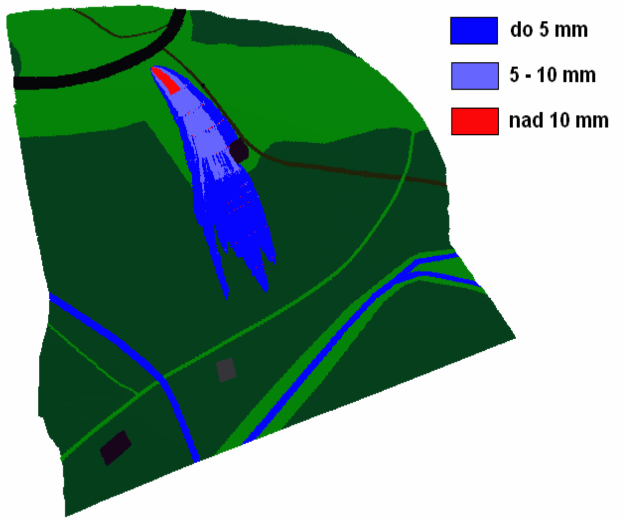

Figure 8: Liquid flashing in the real terrain – pool surface after 660 s

After model infiltration, evaporation and graphic update it will be available to use the developed software for environment elements risk evaluation So far it is not clear, if it will be possible to do calculations for every road parts, or only for chosen places, where the surface waters exposure come on force

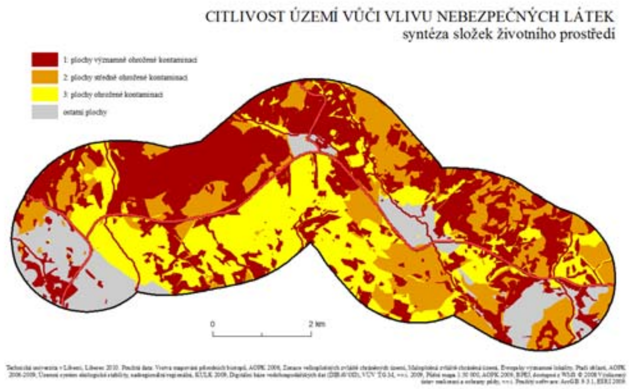

Figure 8: Territory sensitivity against dangerous substances effect, synthetic map.

7 Conclusion

In this paper there is presented present form of operation status of the project 2B08011 BIOTRA Ministry of educations Czech Republic.

The research team is in this time in the first half of project solution and that is why there are presented only partial project outcomes, which show today's work flow on the complex software tool, which will make possible to simulate environment exposure from dangerous substance transport. It enables to determine individual and social risk form stationary and mobile sources. On the basis of these data it is possible to confront each transport variants and investment projects.

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