Hydrogeology as parameter included into the model for risk assessment of hazardous materials transport

Vključitev hidrogeoloških parametrov v model za ocenjevanje tveganja pri prevozu nevarnega blaga

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Abstract: Due to industrialisation and simultaneous increasing heavy traffic is the risk assessment of hazardous materials transport more and more important. Ecologically is Slovenia relatively sensitive area. At least 40 % of Slovenian surface is composed of vulnerable karstic region with permeable rocks, which contain important groundwater resources. The article points out a method and the results of risk analysis for two hazardous materials on selected part of road network. The purpose of this paper is to expose the necessity of incorporation of hydrogeological factor into a model for analysis and risk assessment of hazardous materials transport. Hydrogeological factor was defined (in the same manner as other factors) by the available data for Geographical Information System (GIS) environment. At a later stage it is also possible to incorporate other attributes in the model and to change the weights at particular factors.

Izvleček: Z naraščajočo stopnjo industrializacije in hkrati z večanjem tovornega prometa postaja ocenjevanje tveganja pri prevozu nevarnega blaga vse bolj aktualna tema. Slovenija predstavlja z vidika varovanja okolja razmeroma občutljivo območje. Dobrih 40 % površine države sestavljajo lahko ranljiva kraška področja s prepustnimi kameninami, v katerih so pomembne zaloge pitne vode.V prispevku je prikazan postopek in rezultat analize vrednotenj tveganj za dve nevarni snovi na izbranem delu cestne mreže. Pri tem smo pokazali možnost vključitve hidrogeološkega faktorja v model za analizo in vrednotenje tveganj pri prevozu nevarnega blaga. Hidrogeološki faktor smo tako kot ostale, opredelili z razpoložljivimi podatki v obliki podatkovnih plasti v okolju GIS. V model je možno naknadno vključiti tudi ostale dejavnike in spreminjati uteži za posamezne faktorje.

Key words: Hazardous materials, transport, risk assessment, hydrogeological factors, hot spots, route preferences

Ključne besede: Nevarne snovi, transport, ocenjevanje tveganja, hidrogeološki faktorji, nevarne točke, izbira poti

Introduction

Transportation of hazardous materials is an extensive and complex field of work, which is growing international problem. An increasing number of transportation accidents involving hazardous materials have occurred worldwide. The transport of hazardous materials, such as oil and oil products, liquefied petroleum gases, chlorine gas, pesticides, chemicals and radioactive materials is the potential for incidents and accidents which may result in death or injured people, property damage or damage to the biophysical environment through the effects of fire, explosion or toxicity.

Risk assessments of hazardous materials transport have recently emerged as critical need and several models and approaches have appeared[1-9]. Risk assessment of hazardous materials transport can be conceptualized as consisting of the following activities:

- identification of the type and volume of hazardous materials transported,
- definition of transportation route,
- the nature of the threat to the environment and population of potential release,
- the estimation of road safety,
- the estimation of probabilities of hazardous materials accidents and chemical release,
- the consequences of release.

It is relevant to note that transportation systems are dynamic systems with many external variables (e.g., drivers, traffic conditions, etc.) and it is difficult to bring them into one overall control system.

The purpose of this paper is to introduce the model and to expose the possibility of incorporation of hydrogeological factor into a model for analysis and risk assessment of hazardous materials transport. The article points out a method and the results of risk analysis for two different hazardous materials on selected part of road network.

Hazardous materials and their transportation

Hazardous materials are substances, which, if uncontrollably released into environment, threaten the lives and health of people and animals, cause destruction or damage to property, and have harmful effects on the environment. System of classification of dangerous goods follows the Recommendations on the Transport of Dangerous Goods, published in a document popularly known as the "Orange book"[10]. This system, designed to apply world-wide to all transport modes, assigns the goods to nine different classes according to the main type of danger they could present in transport (explosion, toxicity, etc).

The greatest potential dangers that are found in the largest quantities in Slovenia are flammable liquids (84 %), caustic products (4.8 %), toxic products (3.5 %) and flammable solid materials (2.4 %)[11]. Petrol is the most commonly transported product. The accurate data about transported quantities of dangerous goods on Slovenian roads are not known. The most burdened roads with oil transport are Koper – Kozina, Starod – Kozina, Jelšane – Postojna, and the area near Lendava.

Legislation which deals with the transport of dangerous goods is comprehensive. The fundamental rules concerning the transport of hazardous materials in Slovenia are in “Law about transport of dangerous goods”, in which conditions and works with reference to dangerous goods are defined[12]. In the law is appointed that for transportation of hazardous materials in Slovenia the ADR is applied[10]. ADR is an Agreement drawn up by the United Nations Economic Commission for Europe in Geneva, whereby most states in Europe have agreed common rules for the movement of dangerous goods by road across their frontiers and through their territories.

Methods for risk assesment model

Slovenia represents a relative sensitive area considering road safety. The level of road safety in Slovenia in comparison to the other states in Europe is comparatively low. Every year more than 250 people loose their lives and more than 14 000 are injured in road accidents on Slovenian roads[13,14]. Although the number of accidents that involve hazardous materials is relative low, every blackspot (considering traffic accidents in general) on the state road network represents a potential dangerous point where the probability for the accident is greater than on the other parts. The incorporation of this factor into the model for risk assessment of hazardous materials transport enables better estimation of vulnerability of road network.

The classical approach of assessing risk to man and environment, following a potential transport accident, is to consider the accident frequency associated to a given route segment, population and specific environments (forest, river, etc.) at risk within the corridor created by a relevant impact radius. An effective tool for a probabilistic risk analysis and risk assessment of transportation hazardous materials is the identification and use of “hot spots”. Hot spots are defined as locations with both high accident probabilities and high exposure consequences[4].

The preparation of a risk analysis requires:

- obtaining information on hazardous materials movement, population density, environmentally sensitive areas, road characteristics, and road safety data (Figure 1);
- mapping the data collected;
- determining the types of hazards present;
- identifying vulnerable areas;
- calculating the risks.

In our work, Figure 1 shows the basic factors that were included into our model for risk assessment of hazardous materials transport. In comparison with the models, described in Slovenian literature, we additionally include the factor of road safety and more precisely defined environmental and social factors. Special attention was focused on hydrogeological factor.

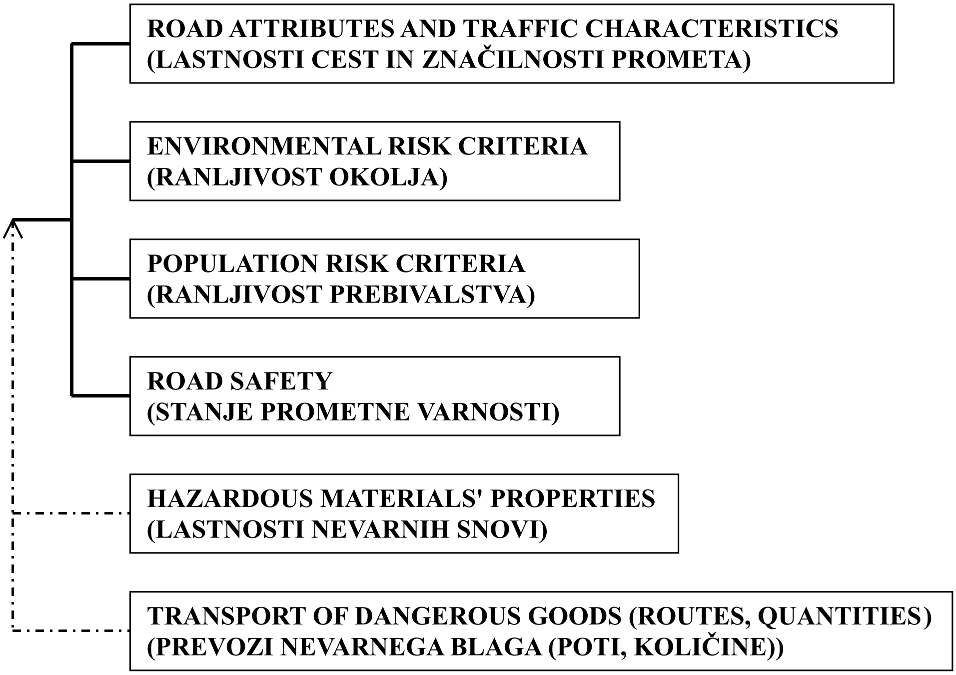

Figure 1. The basic factors included into the model for risk assessment of hazardous materials transport
Slika 1. Osnovne skupine dejavnikov, ki so bile upoštevane v modelu za oceno tveganja pri prevozu nevarnega blaga

The model for hazardous materials risk analysis was formulated as follows:

$$R = a I_{R,T} + b I_{RS} + c I_P + d I_E$$

where
R – risk assessment of hazardous materials transport
a, b, c, d – weights for particular indicators, c,d = f (hazardous materials properties)
$I_{R,T}$ - indicator for road and traffic characteristics
I_{RS} - indicator for road safety
I_P - population risk indicator (damage to people and property)
I_E - environmen t risk indicator

Each indicator was calculated according to next equation:

$$I = \Sigma W_j P_j / \Sigma W_j$$

where P_j is the rating of each parameter and W_j is the weight of the chosen parameter.

The most important factors incorporated into the indicator for road and traffic characteristics were type of roads, level of service, structural and geometric adequacy of roads, traffic volume and composition, availability of alternative emergency route, axle load restrictions, number of intersections, bridges and tunnels. Factors that influence routing risk assessment, from an environmental safety viewpoint, were grouped into three categories: hydrological and hydrogeological data, land use risk (forest, cultivated fields, protected landscape), and subjective factors that reflect community priorities (e.g., special land uses, routing, emergency response). Population risk indicator included population density in the risk zone along the road, and exposed places where a lot of people stopped (parking places, commercial centres, hospitals, schools, etc.). For road safety analysis the data of road accidents (in the years from 1994 to 2000) were used. On the basis of accident rates for heavy traffic, the blackspots – locations with greater number of road accidents - were determined.

Finding the minimum risk routes with realistic assumptions requires the computation of the risk of many individual links. The road network was divided into 300-meter road fragments. The length of a link was determined in accordance with the analysis of road safety, where the 300 m links showed an optimum length for the analysis. For each segment the risk assessment of hazardous materials transport (R) was calculated.

Recent advancements in computing technology, Geographical Information System (GIS) and related databases make this problem computationally feasible. Although this makes mathematical analysis of the model quite simple, the practical significance of the result is relative high. The principles of the described methodology can be easily applied to calculation risk assessment of chosen route for different dangerous goods as well to the risk comparison between two or more alternative routes between an O-D pair.

A lot of attention should be focused on the protection of water from impacts of roads. Slovenia is rich with ground water and almost the entire supply of its drinking water is gained from aquifers. By now, 22 % of the country's surface has already been covered with – actual or proposed – water protection zones[15]. This high concentration of water resources triggers also the demand for their protection.

In Slovenia, porous aquifers are predominant, covering 22 % of the country and occurring in the tectonic depressions and valleys in the central and north-eastern part of the country. They represent major water resources for the population living in the bigger cities. Karst aquifers in limestone rocks cover about 32 % of the area and mainly occur in the southern and western part of the country. Aquifers with fissure porosity are very similar to karst aquifers and cover about 15 % of the countries area. Double porosity rocks build 11 % and low permeable rocks build 20 % of the country[15]. The analysis of interaction between roads and aquifers shows that state roads and highways mainly cross intergranular aquifers.

In the case of an incidental pollution the karst aquifers are the most endangered. At least 42 % of Slovenia represents karst area, which is very sensitive to the pollution. Released hazardous materials from a potential crash site may be transported in several directions up to 30 km far and thus pollution may reach numerous karst springs even such that are captured for drinking water supply[16]. This is the reason why groundwater protection from toxic pollutant releases is specially emphasized.

The following hydrological and hydrogeological factors were included into the model:

- surface waters;
- hydrogeological characteristics;
- protected water resources;
- protection zones of groundwater resources.

Results and discussion

The objective of this paper was to determine the risk (or "hot spots") on selected route for transporting a specific hazardous material between a point of origin and a point destination (O-D pair). The south-western part of Slovenia was selected as the study area, accurately a road between Kozina and Koper (Figure 2). Two classes of hazardous material, oil (with oil products) and oxygen were chosen.

Selected region represents very vulnerable area, especially from the environmental standpoint. The traffic volume on this road

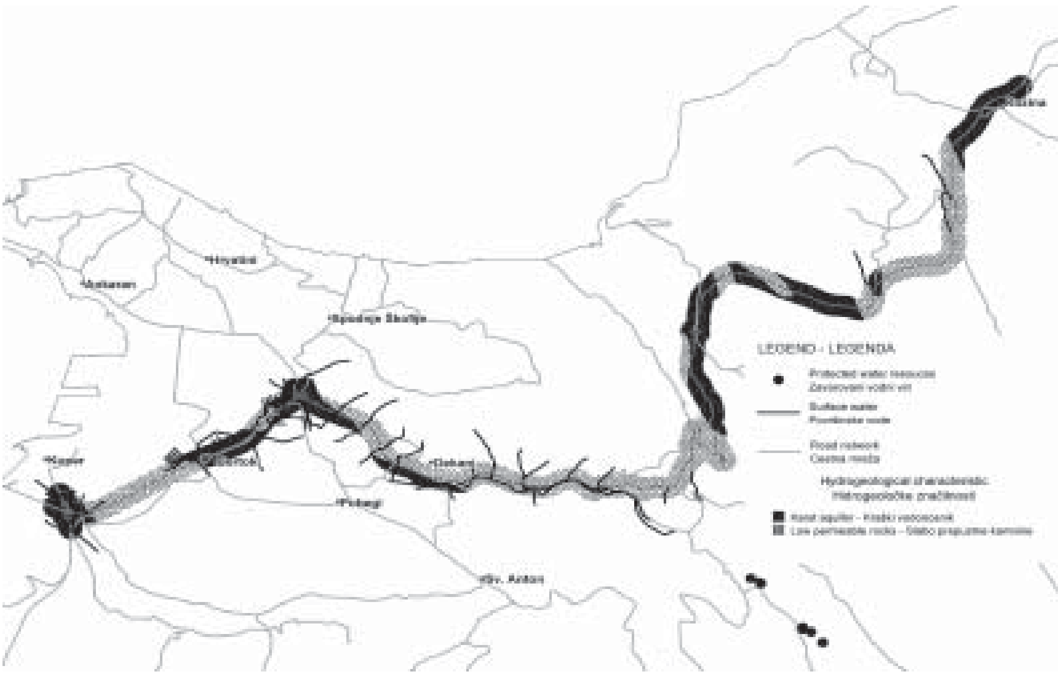

Figure 2. Hydrogeological characteristics on selected area
Slika 2. Hidrogeološke značilnosti na obravnavanem ozemlju

is very high, with more than 100 heavy vehicles with oil per day and 18 heavy vehicles with oxygen per month. Oil and oxygen as hazardous materials have different impact on water and water resources. While oil and its products are very toxic materials for water pollution, oxygen has relatively no effect on water. The potential area of impact was estimated on 200 m on each side of the road[5]. Figure 2 shows hydrological and hydro-geological characteristics on selected area.

A risk route model was developed to determine the risk between an O-D pair by using all factors mentioned earlier (e.g., environment, population, road and traffic characteristics and traffic safety). The risk units for each link were computed and graphically presented on Figure 3 and 4 for oil and oxygen respectively. The results showed that between the same O-D pair, the minimum risk routes were different for various hazardous materials. As expected, the risk assessment for oil transport was on average higher than the risk assessment for oxygen transport. Links with high risk assessment were determined near Kozina, then between Dekani and Bertoki and on the road that cross Petrinjski kras (Figure 3). The risk assessment for oxygen transport showed very low risk for the entire route (Figure 4).

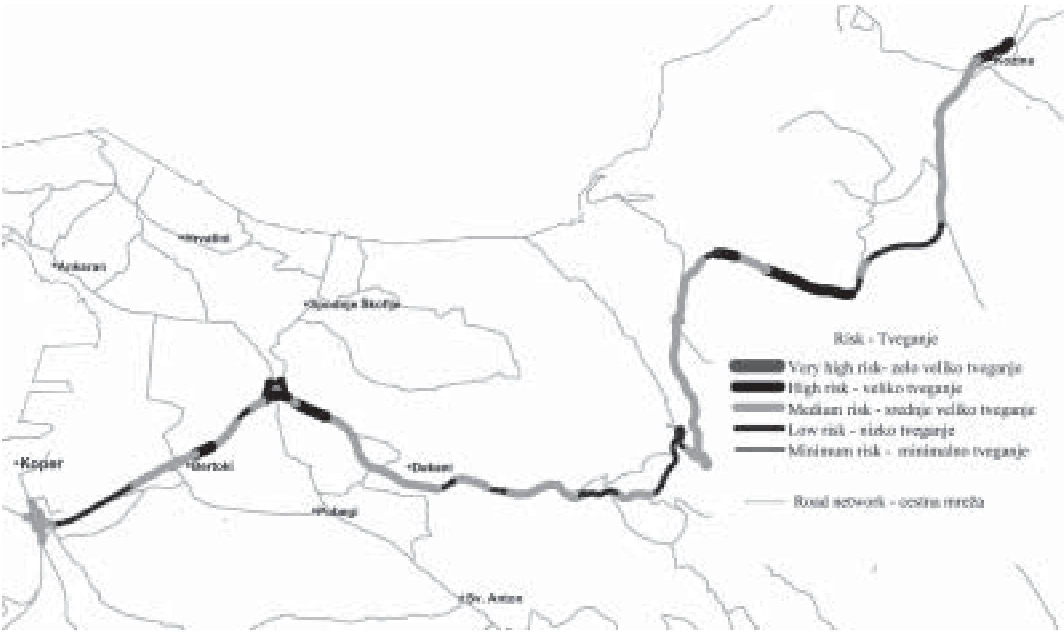

Figure 3. The risk assessment for oil transport
Slika 3. Ocena tveganja pri prevozu nafte

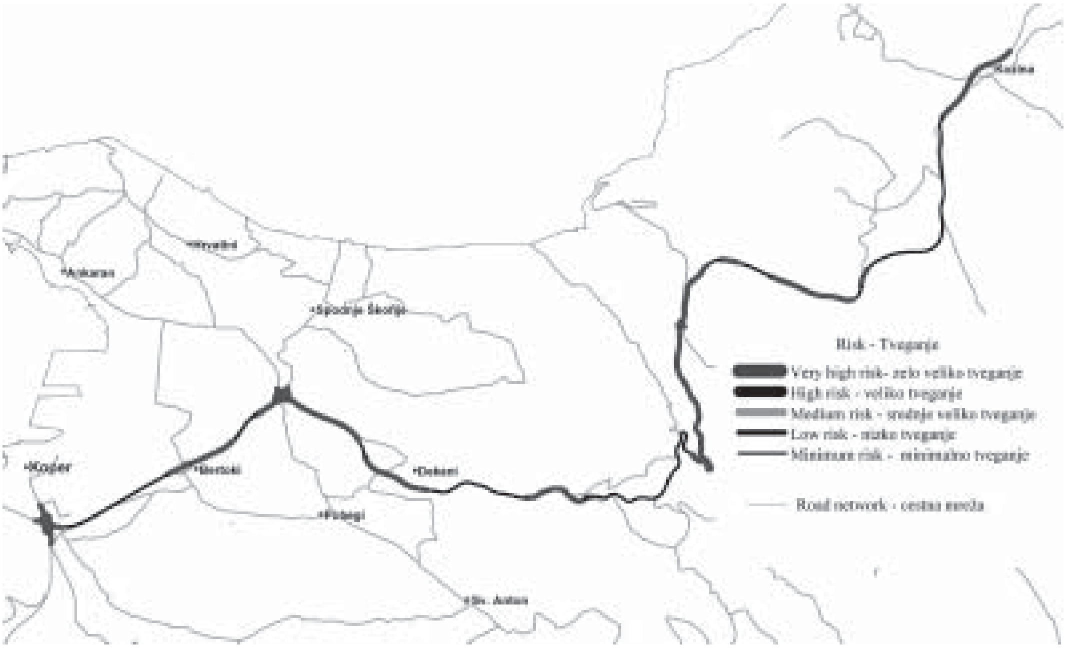

Figure 4. The risk assessment for oxygen transport
Slika 4. Ocena tveganja pri prevozu kisika

CONCLUSIONS

Increasing awareness of hazardous material incidents and potential catastrophic consequences has lead to concern over risk mitigation and activities that are directed toward preparedness planning. A model for risk assessment of hazardous materials transport was presented on the case of two dangerous goods on defined route. Special attention was focused on environmental factors, particularly on hydrogeology. The approach was applied to the risk of route in the south-western part of Slovenia.

Results shows that model represents quite simple but powerful tool for risk assessment of hazardous materials transport. The ability to define and compare different routes for the same dangerous goods or different dangerous goods for the same O-D pair in the model has strong significance for planning and hazard management.

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Povzetek

Vključitev hidrogeoloških parametrov v model za ocenjevanje tveganja pri prevozu nevarnega blaga

Prevoz nevarnih snovi predstavlja povsod v svetu velik problem. Prevoz je namreč dinamičen proces, podvržen spreminjajočim se pogojem ter nepredvidljivim dogodkom. S povečanjem števila prevozov se povečujeta tudi obseg in teža prometnih nesreč vozil, ki prevažajo nevarno blago. V primeru prometne nesreče pri prevozu nevarnega blaga sodi znaten del države med občutljiva področja že zaradi naravnih in družbenih danosti. Slovenija ima npr. razmeroma veliko gosteje poseljenih področij, dobrih 40 % površine države pa predstavljajo lahko ranljiva kraška področja s propustnimi kamninami, pod katerimi so pogosto zaloge pitne vode.

Po zbranih podatkih iz leta 1997 v Sloveniji med nevarnimi prevladujejo vnetljive tekoče snovi (84 %), sledijo jim jedke snovi (4,8 %), strupi (3,5 %), vnetljive trdne snovi (2,4 %), deleži ostalih nevarnih snovi so relativno majhni. Med posameznimi nevarnimi snovmi prevladujejo naftni derivati, stiren, kalcijev karbid, metanol, formaldehid, natrijev hidroksid, ksilen in žveplo. Večina nafte, potrebne za oskrbo Slovenije, prihaja iz pristanišč v Kopru in na Reki. Posledično to pomeni, da so najbolj obremenjene ceste, ki vodijo iz teh pristanišč (odseki Koper-Kozina, Starod-Kozina in Jelšane-Postojna). Drugo območje, ki je močno obremenjeno s prevozi nafte in naftnih derivatov, je Prekmurje – zaradi rafinerije nafte v Lendavi.

Natančni podatki o prepeljanih količinah nevarnih snovi po cestah v Sloveniji še niso zbrani, razen za tiste snovi, za katere je pred prevozom potrebno dobiti dovoljenje pristojnega organa (strupi, eksplozivne in radioaktivne snovi). Te snovi pa predstavljajo le manjši delež v skupni količini prepeljanih nevarnih snovi po cesti. Kot smo že omenili, daleč največji delež odpade na vnetljive tekočine, predvsem nafto in njene derivate.

Stanje prometne varnosti v Sloveniji je v primerjavi z Evropo na razmeroma nizki ravni. Število nesreč z udeležbo vozila z nevarno snovjo se glede na analizirane podatke giblje med 19 in 36 nesreč na leto. Letno se v povprečju zgodi po ena prometna nesreča, v kateri se razlije večja količina nevarne snovi, najpogosteje nafte in njenih derivatov. Poleg nafte so se v devetdesetih letih razlile še manjše količine ocetne kisline, klorovodikove kisline, različnih barv in lakov ter butana.

Namen raziskovalne naloge je bil izdelava modela, s pomočjo katerega lahko ovrednotimo tveganje pri prevozu nevarnega blaga na državnem cestnem omrežju. V skladu z mednarodnimi trendi na področju metod ocenjevanja tveganja je bil eden od ciljev naloge v primerjavi z doslej narejenimi raziskavami in metodami v Sloveniji uvedba določevanja t.i. nevarnih točk. Ta se namreč kaže kot učinkovito orodje za verjetnostno analizo tveganj pri prevozu nevarnega blaga.

Na stopnjo tveganja pri prevozu nevarnega blaga ima največji vpliv vrsta in lastnosti nevarne snovi, ki jo prevažamo. Vsak razred nevarne snovi predstavlja različno močan potencialni vir nevarnosti za posamezne vrste ogroženih področij (npr. zrak, voda, tla, ljudje). Čim večja je količina prepeljanega blaga (število vozil, ki vozijo nevarno blago), tem večje je tveganje. Zato je pri oceni tveganja pomembna količina in vrsta prepeljanega blaga ter izvor in cilj prevoza. V model za ocenjevanje tveganja smo poleg vrste in količine nevarnih snovi vključili tri osnovne skupine dejavnikov (slika 1):

- lastnosti cestne mreže in prometa,
- ranljivost prostora in
- stanje prometne varnosti.

Med lastnostmi cestne mreže smo upoštevali vrsto in opis ceste, njene tehnične lastnosti, vrste in število objektov, število možnih "izvoznih" cest, omejitve osnih obremenitev in število križišč. Kot ranljivost prostora smo opredelili naravne in človeške danosti v vplivnem območju od cesti in sicer hidrogeološko podlago, vodotoke, zaščitene vodne vire, kmetijske in gozdne površine, zavarovana območja naravne in kulturne dediščine, gostoto prebivalstva ter področja ob cestah, kjer se običajno zadržuje več ljudi (izobraževalne in zdravstvene ustanove, nakupovalna središča, večja parkirišča, bencinski servisi itd.). Za oceno stanja prometne varnosti smo uporabili bazo prometnih nesreč za obdobje sedmih let (od 1994 do 2000). Zaradi nepopolne baze podatkov o nesrečah pri prevozu nevarnega blaga, smo opravili analizo prometnih nesreč na nekoliko širšem razredu vozil – vseh tovornih vozilih. Končni rezultat analize so deli cestne mreže, t.i. črne točke, kjer se je v preteklosti zgodilo večje število prometnih nesreč z udeleženimi tovornimi vozili.

Vsaka prometna nesreča vozila, ki prevaža nevarno blago, ima lahko za posledico sproščanje nevarne snovi v okolje. Eden od najbolj občutljivih delov okolja za onesnaževanje je voda. Po površinskem vodotoku se izlita nevarna snov lahko prenese na daljše razdalje, lahko pa skozi tla in kamnine pronica v podtalnico in onesnaži zaloge pitne vode. Zato je prav hidrogeološki vidik pri ocenjevanju tveganja nevarnega blaga eden od najpomembnejših. Hidrogeološki faktorji, ki smo jih v dosedanjem delu na podlagi razpoložljivih podatkov vključili v model, so: hidrogeološke lastnosti vodonosnika in njegova prepustnost, zaščiteni vodni viri ter površinska vodna mreža.

S pomočjo modela lahko za vsak razred nevarnih snovi in za vsako pot na državni cestni mreži (izvor – cilj) določimo nevarne točke. Prav tako lahko z uporabo modela izbiramo med več alternativnimi potmi in se odločimo za najvarnejšo (pri čemer "najvarnejšo" pot najprej definiramo). Predstavili smo primer izračuna za prevoz dveh nevarnih snovi (nafte in njenih derivatov ter kisika) med Koprom in Kozino. Cesta predstavlja pomembno prometno povezavo koprskega pristanišča z zaledjem in po njej se vsak dan prepelje velika količina nevarnega blaga.

Najprej smo celotno cestno mrežo razdelili na 300 metrske kose in vsakemu kosu pripisali z uporabo orodij GIS kazalce, s katerimi smo opisali lastnosti vozišča, prometa in prometne varnosti. Vsaka od obravnavanih dveh nevarnih snovi ima drugačen vpliv na ranljivost prostora, zato smo v model za vsako snov posebej definirali različne kazalce vpliva. Končni rezultat vrednotenja modela so slike, na katerih so posamezni 300 metrski kosi ovrednoteni glede na tveganje prevoza za posamezno snov (sliki 3 in 4).

Metodo lahko tudi uspešno uporabimo pri primerjavi in izbiri med več alternativnimi potmi in na podlagi rezultatov vrednotenja izberemo tisto, ki je najbolj varna z vidika tveganja za ljudi in okolje.

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