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How to Calculate the Accident Probability of Dangerous Substance Transport

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Abstract

Currently the risk assessment of dangerous substances manipulation and transportation is a frequent topic in scientific groups. It exist many themes from this area, which are discussed at conferences and scientific events. One of these topics is surely the calculation of accident probability of dangerous substance transport. The following paper describes the procedure of the accident probability calculation of dangerous substance road transportation. The next aim of this paper is to show, what uncertainties may be contained in such as calculation procedure. And finally, which parameters should be collected for complex accident risk assessment of dangerous substance road transport.

1. Introduction

Dangerous substance transport is a big problem in term of environment potential pollution. History showed many large accidents, which cost many human lives and caused large human health and resources damage. In this paper we will focus on dangerous goods road transport. It will be presented some ideas, how to collect data for need of dangerous goods road transportation assessment in the Czech Republic.

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We need two types of necessary information:
- traffic accident evidence,
- transport output statistics.

It means the number of traffic accidents and kilometres travelled by dangerous goods transport on roads. There is a different situation in both of these areas. It exist much traffic accident evidence, but they are contradictory. The basic data about travelled distances by dangerous goods transport are missing. So, here we can use the research to fix the existing problem.

At this time the data collection for traffic infrastructure and further risk assessment purpose is unsystematic in the Czech Republic. Here are some types of useable data in the area of dangerous goods transport, which are missing:
- accident frequency,
- transportation outputs,
- traffic accident causes and consequences.

That is the reason why it is impossible to quantify parameters describing transportation risk rate in the Czech Republic. It is important to say, that the traffic accident may cause fatal consequences for human and the environment [1]. The risk rate largely depends on transport outputs, way kinds and accident rate. The accident probability get from the accident rate is then directly dependent on monitored data quality about transportation.

2. Risk in General Case

There are many formulas, which are used for calculation of some kind of risk. But one risk formula is the base for every next risk calculation.

$$R = P \cdot N \tag{1}$$

Where:

R – risk,

P – undesired event probability,

N – event consequences.

The whole risk evaluation is dependent on evaluation of both of above mentioned parameters. At this time it exist many methods and procedures, which describe specific scenarios consequences assessment connected with dangerous goods outflow to the environment. And there is a catch, because the quantification on the side of accident probability is practically missing. And here the idea to build up a frequency data collection methodics was born. The next figure shows the diagram of risk assessment by dangerous goods transport.

2.1. Dangerous goods transport risk model

The basis for the dangerous goods transport risk model is expressed from the general risk model mentioned above [2, 3, 4, 6, 7].

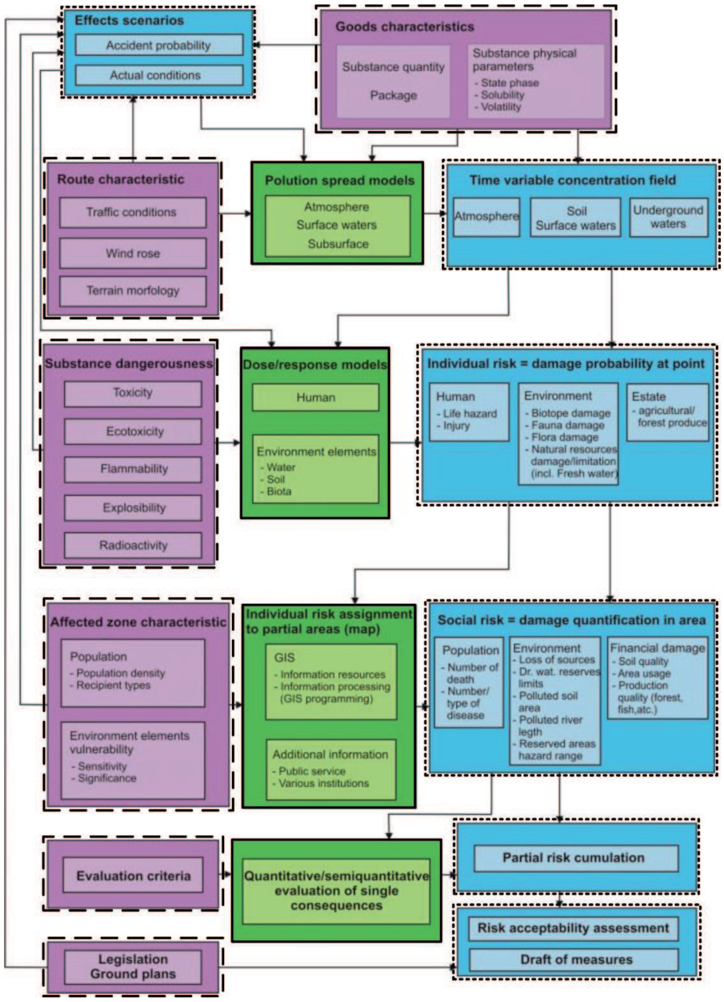

Fig. 1. Human and environment risk assessment by dangerous substance transport

Explanation

– – – = input parameters, —— = models, - - - - - = single evaluation steps.

Basic input parameters take an information about dangerous substance volume, chemical and physical parameters and substance dangerousness. Next input information are transport route characteristics in given area (cant and directional rates, relief morphology and weather conditions).

3. Accident Frequency Data Collection in the Czech Republic Nowadays

Traffic accident evidence is very unsystematic in the Czech Republic now. There are different state and public administration elements which keep differently oriented record. Most considerable evidences are two:

– Ministry of transport of the Czech Republic,
– Police Head Quarters.

Table 1

Total number of road accidents with dangerous goods participation [1]

Road transportation			Consequences category - road accidents					
Group	**Substance**	**Road accident total**	**Traffic accident**	**Substance outflow**	**Fire with partici-pation**	**Fire without partici-pation**	**Work with water**
A	**Ammonia**	**285**	**5**	**135**	**96**	**47**	**2**
B	Coal-oil	3606	3119	389	45	46	7
B	Coal-oil prod.+ crude oil	362	325	19	3	12	3
B	Liquid hydrocarbons	14	6	4	3	1	
B	**Oil products - total**	**3982**	**3450**	**412**	**51**	**59**	**5**
C	**Gas**	**3646**	**3215**	**312**	**46**	**68**	
D	Hydrochloric acid + Hydrogen chloride	208		103	13	89	3
D	Phosphoric acid	15		6	1	8	8
D	Sulphuric acid	183	5	83	4	83	
D	Nitric acid	66		36	3	27	1
D	Acid	13		5		7	12
D	**Acid - total**	**485**	**5**	**233**	**21**	**214**	**1**
E	Bottle gas	311	10	106	186	8	
E	Butane	13		7	6		
E	Butadiene	4		3	1		
E	Propene, propylen	50		27	12	11	
E	Propane	24		11	12	1	
E	Methane, natural gas	1105	10	432	648	10	5
E	**Gases**	**1507**	**20**	**586**	**865**	**30**	**6**
F	**Chlorine**	**67**	**1**	**30**	**32**	**3**	**1**

However general data are largely different. The statistics of travelled distances with dangerous goods do not exist at all. Necessary values for risk assessment are deduced from indirect data. Most values are only estimated. Here is possible to pick up on the project of Ministry of Transport of the Czech Republic called “Transport dangerous goods management in relation to system crisis management in Czech Republic at the European and national level". This project is focused on the proposal of GPS monitoring equipment for all ADR vehicles. This module will enable monitoring of all ADR vehicles in the road network in the Czech Republic. The GPS monitoring equipment could be also used for calculation of travelled distances with relevant load. But it is necessary to integrate the project outcomes to the real transport.

The risk can be quantificate correctly and complexly only when the system of data collection work well. When all of these assumptions are fulfilled than we could minimalize the risk resulting from dangerous goods transportation for people and the environment. The next table shows the number of accidents caused by dangerous goods road transportation [1].

The next table shows, what kind of data is possible to get in the Czech Republic.

Table 2

Summary of used data sources [1]

Used data	Symbol	Source	The year of source record
The record of dangerous substances outflow consequences by ADR transport – frequency	A	MDČR	Detailed record from 1996-2007
The ADR accident record according to the road type	B	PP ČR	Detailed record from 2003-2008
The record of travelled distances with dangerous substances	C	MDČR	2004 - 2007
The record of freight transport intensity in 2005	D	ŘSD	2005
The total road length	E	ŘSD	2009
The ADR transport frequency get from the freight transport frequency	F	Own record	Average values from partial investigations

Explanation
MDČR Ministry of Transport of the Czech Republic
PP ČR Police Presidium of the Czech Republic
ŘSD Directorate of Roads and Highways of the Czech Republic

4. Specific Model of ADR Accident Frequency

The calculation of ADR accident frequency has many steps, which are mutually connected. The specific model, which you can see on the next figure, shows an accident frequency assessment. The procedure is focused on the calculation of an accident frequency per one travelled kilometre according to the road class. This basic ADR accident frequency is then modified according to traffic intensity and local route conditions (cities, curves, crossings) [4].

For our case, which is the calculation of an accident frequency, we can use a basic formula:

$$F = X/L \tag{2}$$

Where:

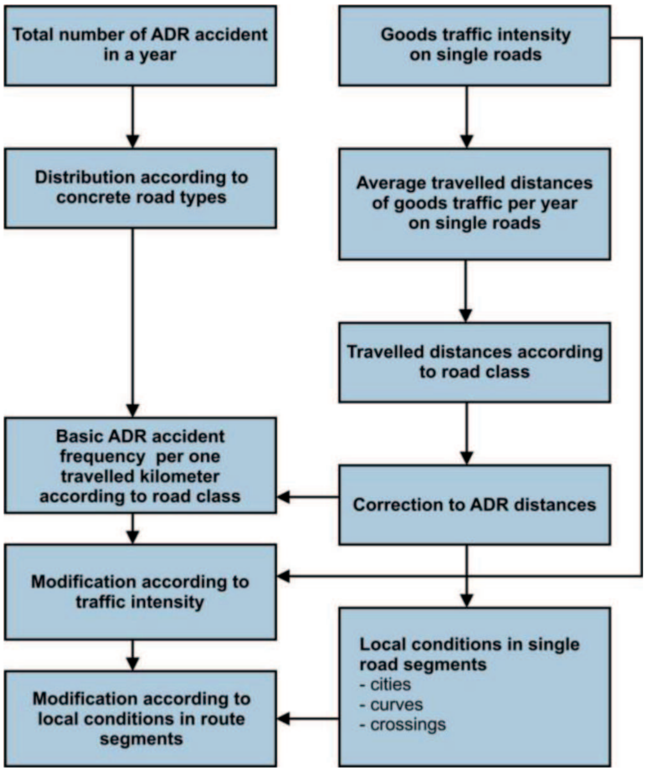

Fig. 2. Specific model of ADR accident frequency calculation on traffic roads

F – is accident frequency of one kilometre segment,
X – number of accident per period,
L – travelled kilometres per period.

This general formula is valid for all types of traffic accidents including goods traffic and ADR accidents. But we must know adequate *X* and *L* in useful distribution for given exercise. The next table shows the results get from the calculation of an accident frequency of one kilometre segment using the above mentioned formula.

Table 3

ADR accident frequency according to road class and type of dangerous substance

	Highway	**1. class road**	**2. class road**
ADR accident frequency per 1 kilometre	$0.199 \cdot 10^{-6}$	$0.538 \cdot 10^{-6}$	$0.881 \cdot 10^{-6}$
Accident frequency for gases	$0.483 \cdot 10^{-6}$	$1.306 \cdot 10^{-6}$	$2.139 \cdot 10^{-6}$
Accident frequency for liquids	$0.104 \cdot 10^{-6}$	$0.272 \cdot 10^{-6}$	$0.462 \cdot 10^{-6}$

5. Modification According to the Local Conditions

Other factors have also impact on accident frequency on single roads or their parts [1]. Here are some of them:

– traffic density,
– transit through cities,
– presence of road crossings, curves and other places with larger accident occurrence,
– daytime or season.

The purpose of the modification is the regulation of value of accident frequency connected with dangerous substance outflow according to the local conditions. In this purpose it is necessary to investigate the accident occurrence in dependence on the traffic intensity and on single road types (highways, 1. class roads, 2. class roads). Then it is necessary to investigate the accidents in cities and out of them and the accidents with the resolution of road local conditions, i. e. accidents at the crossroads, in curves and on the straight parts.

The modification based on completing parameters we realize with the help of modification coefficients. The modification consists in redistribution of accident frequencies between single roads so, that the total frequencies will stay original. That is why the condition necessary for conservation of total number of potential accidents after modification is valid:

$$\sum_i m_i \cdot d_i = 1 \tag{3}$$

Where:

i – road/road segment index,
m_i – modification coefficient for i-segment,
d_i – length rate of i-segment.

The modification can be done in several levels. In the top level it is concerned about modification for single roads and highways, where the total length of relevant road type is the superior unit. In lower levels it is concerned about segments in terms of single roads, eventually about segments of road parts, which are not crossing through cities, etc.

5.1. Modification based on traffic intensity

The reason of this modification is the hypothesis that the accident probability increases with the traffic intensity. It is necessary to find useful functional relation between these parameters and to use it by accident probability modification. It is possible to use the rate of traffic intensity on relevant roads and average intensity on roads of given type like a modification coefficient for highways.

5.2. Modification based on accident site character

Accident frequency is affected by many factors. Except communication type (highway, first/second class roads) and traffic intensity on single roads, is the accident frequency affected by roads specific character. Transit through cities is the separate problem. So it is necessary to do modification for road segments in cities and out of cities first. The second step will be the modification based on critical parts of the roads outside the cities, such as road crossings or curves. Most of accidents take place in cities (based on MV ČR and PP ČR statistics). The statistics is related to all accidents. Surely personal motor cars are dominated in these statistics. Car traffic in cities and especially in big ones has different character than outside the cities. For our problem are important especially these facts:

– different traffic rules in cities, important is especially speed limitation to 50 km/hour,
– in big cities the length of streets and minor roads is larger than the first class road crossing through the city,
– many cities has constructed by-pass roads,
– in cities there is strongly lower rate of goods traffic against personal transport than on roads outside the cities,
– ADR transport keeps away from cities, if there is no transport start or end.

Based on this information it is possible to suppose, that the ADR transport rate on city roads and streets is largely lower than on first/second class roads. It is possible to suppose, that the rate of major ADR traffic accident will be in cities minor because of the speed limit. By this speed limit it is clear, that the possible accident will have lower consequences. From my point of view are important first/second class roads segments, witch are going through smaller cities and simultaneously these roads present city main road.

5.3. Critical places outside the cities

Next critical places of accident frequency are road-crossings, curves, straight segments and road upgrade and downgrade [2, 7]. The numbers of traffic accidents according to critical places on single road types in 2009 shows the table 5. Accident probability modification based on critical places (road-crossing) will be done only for segments outside the cities. Here it will be the modification coefficient determined by the values of rate of segments length with crossings, curves and other critical places to total length of concrete road. In the following table there is mentioned the accident frequency on the single roads with the resolution of accidents place (in or out of cities). According to this statistics the accident rate in cities is more than twice as big like outside the cities.

Table 4

The accident frequency in cities and outside the cities

The accident frequency in road transport (2009)	The number of accidents	Accidents	
		In cities	Outside the cities
Traffic accidents in total	75011	52449	22561
Traffic accidents – freight transport in total	10517	6649	3885
- highways	532	0	545
- 1. class roads	2440	871	1556
- 2. class roads	1551	658	894
- 3. class roads	1187	574	615

Table 5

Critical places of traffic accidents according to the traffic accidents record in 2009

		Accidents outside the cities according to critical places			
Frequencies of road transport accidents	Accidents outside the cities in total	Straight part	Straight parts after the curves	Curves	Crossings
Traffic accidents in total	22561	11562	3290	5033	2538
Traffic accidents – Freight transport	3885	2356	423	705	387
- highways	545	523	6	11	4
- 1. class roads	1556	965	139	247	194
- 2. class roads	894	382	160	234	116
- 3. class roads	615	300	98	167	49

5.4. Modification based on natural conditions

Natural conditions form important concern in possibility of accident happening on the road. For this purpose it exists road signalling, which warn of larger possibility of accident. Increased accident risk evokes natural conditions, which have straight impact on vehicle movement. They are more or less random type with the meteorological prognosis for several days. So it is the reason, why it is not possible to do the modification based on natural conditions (rain, snow, icing, fog, strong wind) generally and it is possible to do this only for the locality known in advance. It is concerned primarily about natural conditions.

5.5. Self proposal for data collection

The main aim is to collect data about transport which should be consistent and not contradictory [1]. For this it is necessary the cooperation of emergency service elements, state administration and other concerned units. In the Czech Republic it exist many statistics oriented to accident frequency. The data from these statistics are in many cases overlapped in content (sometimes are contradictory), but most of required data are missing. The summary data from single databases and statistics are not sufficient for complex risk assessment of ADR transport and its partial aspects. The main proposal is the statistics completion about relevant data and a proposal of system of data collection by the public service units with its uniform interpretation ensuring. The data structure will be created by data necessary for complex risk assessment of ADR transport. This data structure will be proposed by single emergency service units, state service and concerned institutions.

Table 6

Example of list of relevant data necessary for accident risk assessment by dangerous goods transport on the traffic roads in the Czech Republic

Kind of parameter	Parameter of data collection
Road tank description	Vehicle volume
	Vehicle type
	Vehicle marking
Load	Substance mark
	Substance quantity
	Conditions (pressure, temperature)
Accident reason	Natural conditions (icing, snow, rain, etc.)
	Human error
	Technology failure
	Intention
Accident consequences	Death
	Injury
	Estate affection
	Environment affection
	Outflow reach, working fluid outflow
Accident place	Curve
	Road-crossing
	Road upgrade/downgrade
	Bridge
	Grade crossing
	Road category
	City/outside the city
Route	START (place, time)
	END (place, time)
	Distance
	Road class
Accident time	Accident time
Accident Date	Accident date
Additional information	

The unwanted event in transport (accident) includes many parameters, which are necessary for complex risk assessment of traffic infrastructure. From these parameters it will be created a form, which will be presented for usage of subjects, which are participating on accident statistics for statistical purposes. The form will be accessible online and will cover all aspects of accident in road traffic by its structure. The profit takes effect mostly in traffic infrastructure risks identification. The second profit is in uniform data collection system creation. The resulting profit will be the accident probability prediction by dangerous goods transport. The next table shows some data types, which should be collected for ADR accident frequency evaluation. For accident risk quantification by ADR transport is important anything else. It is total travelled distance on single traffic roads by vehicles which transport dangerous goods. At this time these data are not available. It is possible to propose a system of ADR vehicle monitoring, which will be realized by the GPS online monitoring equipment. The data from this equipment will be recorded to the database for other usage. This proposal will be consulted with transporters, emergency service and state administration specialists.

The responsibility for data putting should have the transporter. The data about the route should be more detailed, which will depend on the type of used equipment. (excepting START end END marking by the driver the information flow must be automated).

6. Conclusion

The data collection organization for the purpose of complex risk evaluation of traffic infrastructure has to proceed by the participation of interested units (emergency service, state administration). When the traffic accident happens, all data will be recorded according to the list of relevant proposed data.

The record will proceed by the help of electronic form, which will be online accessible for all participating organizations. The unification of each record will be conserved. The form will be online imported to the designed database application for future usage.

Acknowledgement

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