PROBABILITY ASSESMENT OF CORRECT ADR VEHICLE LABELLING USING BAYESIAN STATISTICS

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Summary: This article is focused on theoretical and mathematical assessment of the probability of correct labelling of vehicles transporting dangerous goods according to the international ADR agreement. The calculations used the principles of Bayesian statistics and general knowledge of the theory of probability. For the mathematical part of the solution were used statistical data on the transport of dangerous goods in the Czech Republic. In conclusion there are suggested possible links and implications of the findings.

Key words: Bayesian statistics, dangerous goods,accident, risk.

INTRODUCTION

Dangerous substances and goods are according to the czech legislation defined as substances, which may by their very nature, quality or condition in connection with the transportation cause a lot of risks, such as safety of persons, safety of animals, things, or may cause some environmental risks (1). Similar definition of dangerous substancec and goods is used by the U. S. Department of Transportation which defines these materials as any substances or materials which may cause harm to persons, property or to environment (2).

It´s obvious, that not only production, but any other handling with these substances, especially transportation, during which the subsances are in direct contact with environment, are a potential threat to all entities such a people, animals or environment. Despite of this fact there are thousands types of dangerous goods which are beeing transported on daily baisis - explosives, gases, flammable liquids, flammable solids, oxidizing substances, toxic, radioactive, corrosive and other dangerous substances (2).

Due to the inherent transportation risks is transport of the dangerous goods ragulated by the law. Each of the transport mode has special regulation, which are under the UN supervision in the Europe. It is the ADR agreement in road transport, RID agreement in rail transport (3). Similar regulations apply also in North America - Federal Hazardous Materials Transportation Act in the United States and the Federal Transportation of Dangerous Goods in Canada (4).

According to the international ADR agreement it is necessary to label the transport unit (vehicle) carrying dangerous goods by orange tables, which shall meet the material and physical characteristics (3). In case of labelling vehicles carrying dangerous goods in tankers or in bulk, the identification tables uniquely defines the substance by a hazard identification number and by a UN number. Among other things, the aim of labelling is to point out the

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increased risk which occurs during the transport of the dangerous goods. The ADR agreements specifies exact rules on how orange tables should be mounted on the vehicles.

Risk is usually defined as propability of unwanted event and its consequences (5). Despite the increased caution, the traffic accident may occur when exceeding the level of risk in the transport process. Traffic accidents where vehicles transporting dangerous goods are involved are considered very unlikely, but with big consequences (5). This is the reason why we should pay more attention to this type of transport and have validated statistical data on the transport of dangerous goods and related accidents.

Aim of this work is to set up a procedure for calculation of the probability of correct vehicle labelling according to the international ADR agreement. Vehicles carrying dangerous goods are unfortunately not always well labeled with orange tables for several reasons which are outlined in this work. Wrong or missing label on the vehicle involved in the traffic accident causes complications and thus negatively affects the safety of the transport of the specific goods. Therefore, the main focus will be on usual transport of these things (safe and accident-free), for which we calculate the probability of correct vehicle labelling. For these calculations the general principles of Bayesian statistics will be used. Based on these calculations will be given problem solved teoretically and then will be verified by calculations using statistical data (transport of dangerous goods) of the Czech Republic.

1. BAYESIAN STATISTICS

Bayesian statistics is named after Thomas Bayes and it is based on the assumption that any already known information (aprior) could be combined with the following measurement (posterior) to determine the overall probability (6).

This theorem can be generally expressed as follows:

$$P(A_i|B) = \frac{P(A_i)\,P(B|A_i)}{\sum_j P(B|A_j)\;P(A_j)} \qquad (1)$$

Kde:

$P(A)$ $\quad the\ probability\ of\ the\ event\ A,$

$P(A|B)$ $\quad the\ probability\ of\ the\ event\ A, if\ event\ B\ occurs.$

In this formula it is valid that, events A_j are disjoint and $\bigcup_j A_j = B$. After simplification of the formula (1) we gets formula (2) as follows:

$$P(A|B) = \frac{P(A)\,P(B|A)}{P(B)} \qquad (2)$$

Bayesian statistics differs from classical statistics. It isn´t assuming fixed distribution of all parameters, but it asumes that all parametres are random variables. Bayesian networks are based on Bayesian statistics. They are graphical models that represent a set of variables and their probabilistic relationships (6).

This Bayesian statistic can be used to calculate the actual probability of accidents, where vehicles carrying dangerous goods is involved - „True Accident Rate“. The basic prerequisite for its use is the availability of a sufficient number of statistical data about each type of accident (3).

2. PROBABILITY OF TRAFFIC ACCIDENT

For application of Bayesian analysis it is necessary to determine the probability of event B, if the event A occurs. An event A is in our case the probability of an accident during transport of dangerous goods (ADR) at a distance of 1 km. According the article (7), the prior probability of accident is $P(ACC) = 0{,}000000341$. So the probability of accident-free transport is under the same conditions ($P(NoACC) = 0{,}999999659$ (7).

The informative value of the probability of traffic accident involving dangerous substances is in correlation with quality of the statistical data, from which this probability is calculated. Data on the number of traffic accidents involving vehicles carrying dangerous goods are, unfortunately always affected by a statistical error. The most frequent reason of errors in evaluating whether the accident is really an accident involving a vehicle carrying dangerous goods or not, is a vehicle with wrong orange plate (wrong label). So the probability of the event B is the probability of correct labelling of the vehicle according to the ADR agreement. $P(B) = P(C_{ADR})$.

For the purposes of this calculation we assume that minor mistake in labelling (wrong UN number) won´t be considered as a incorrectly labeled vehicle, even that according to the legislation it will. Follows we will refer to a vehicle that although were labeled by orange plates (with possible minor errors), but in fact, given the nature of the cargo it shouldn´t be labeled as vehicle carrying dangerous goods at all. This term will be furthermore used for vehicles carrying gangerous goods, which are inherently classified as dangerous vehicles (should be labeled by orange tables according to the ADR agreement), but in fact they are not labeled (intentionally/unintentionally) and therefore they visually look like as normal vehicles.

The probability of the correct labelling of the ADR vehicle assuming, that traffic accident (of ADR vehicle) occurs $P(C_{ADR}|ACC)$ can be expressed as follows (3):

$$P(C_{ADR}|ACC) = 1 - P(W_{ADR}|ACC) \quad (3)$$

Where:

$P(C_{ADR}|ACC)$ $probability\ of\ correct\ labeling\ of\ ADR\ vehicle, assuming\ that\ traffic\ accident\ occurs,$

$P(W_{ADR}|ACC)$ $probability\ of\ wrong\ labeling\ of\ ADR\ vehicle, assuming\ that\ traffic\ accident\ occurs,$

For the calculation it is necessary to know or estimate the number of vehicles which are not transporting dangerous goods, which are incorrectly labeled by orange tables as vehicles transporting dangerous goods according to the ADR agreement. ($W_{ADR}|ACC$). This is usually caused by the unintentional driver´s, carrier´s or shipper´s mistake. Because of the fact, that in connection with the transportation of dangerous goods it is necessary to fulfil strict rules (besides other transport), we can not expect that vehicles carrying common goods will be labeled by an orange table according to the ADR agreement. Nevertheless, these errors can occur in all means of transport of dangerous goods (units, tanks, bulk). We can use as an example transport of the empty tank, where driver forgot to remove the orange tables. Transport and possible accident of such vehicle (incorrectly labeled as an ADR vehicle), is perceived as an ADR accident. Other errors may result from transportation of dangerous

goods in packages. In this form of transportation, there are a lot of exception relating to packaging and number of packages per transport unit (sub-limit, limited or excluded volume). Vehicles in these cases are not carrying dangerous goods in full scale, as it is defined in the ADR agreement, but thay can be incorrectly labeled by orange tables, as if it were an ADR transport.

Much more dangerous is situation when vehicle is carrying substances, which are according to the specified ADR criteria considered as dangerous goods, but they are not labeled with orange tables. This situation can occur unintentionally, because of ingnorance or unawareness of the entities which are involved in the transport process (shipper, carrier, driver), but it can also be an intentional mistake unfortunatelly. Despite all of the risk of the wrong identified vehicles, we can assume that due to an effort to reduce some of the cost are those transports normally carried out.

The number of incorrectly labeled vehicles can be determined as follows (4). It is valid, that first term in the formula represents vehicles which are not carrying dangerous goods but were labeled during the accident as ADR vehicles and second term represents vehicles carrying dangerous goods, which weren´t labeled by orange tables. In formula (4) must be all input values regarding the number of traffic accidents related to uniformly set period of time.

$$P(W_{ADR}|ACC) = \frac{ACC_{W\_ADR}}{ACC_{ADR}} + \frac{ACC_{W\_FRE}}{ACC_{FRE}} \quad (4)$$

Where:

ACC_{W_ADR} $number\ of\ traffic\ \ accidents, where\ incorrectly\ labeled\ ADR\ vehicles\ are\ involved,$

ACC_{ADR} $number\ of\ all\ ADR\ traffic\ accidents\ (wrong\ and\ correct\ label\ of\ ADR\ vehicle),$

$ACC_{W_{FRE}}$ $number\ of\ traffic\ accidents, where\ wrong\ labeled\ ADR\ vehicles\ aren´t\ involved,$

ACC_{FRE} $total\ number\ of\ traffic\ accident\ involving\ freight\ vehicles\ (wrong\ and\ correct\ label\ of\ freight\ vehicle).$

When Bayesian statistics are aplied it is necessary to determine the probability of correct labelling of the ADR vehicle, if traffic accident won´t occur $P(C_{ADR}|NoACC)$. To evaluate the probability of this fact we can use the same analogy as in formula (3). After adjusting the formula we will have the following form:

$$P(C_{ADR}|NoACC) = 1 - P(W_{ADR}|NoACC) \quad (5)$$

3. CALCULATION OF THE POSTERIOR PROBABILITY

We will start from the general formula of the Bayes theorem. In this case we have several possibilities (accident/ no accident, vehicle is correctly/ or not labeled according to the ADR agreement). So we get this formula:

$$P(ACC|C_{ADR}) = \frac{P(ACC).P(CS_{ADR}|ACC)}{P(ACC).P(C_{ADR}|ACC) + P(NoACC).P(C_{ADR}|NoACC)} \quad (6)$$

Where:

$P(ACC|C_{ADR})$ $probability\ of\ an\ accident\ of\ correctly\ labeled\ ADR\ vehicle,$

$P(ACC)$ $probability\ of\ ADR\ traffic\ accident,$

$P(C_{ADR}|ACC)$ $probability\ of\ correcly\ labeled\ ADR\ vehicle, if\ traffic\ accident\ occurs,$

$P(NoACC)$ $probability\ of\ the\ safe\ ADR\ transport,$

$P(C_{ADR}|NoACC)$ $probability\ of\ correcly\ labeled\ ADR\ vehicle, if\ save\ transport.$

In the (6) formula, there are two new terms. It is the probability of occuring accident, if the vehicle is correctly labeled according to the ADR agreement $P(ACC|C_{ADR})$ and probability of correctly labeled vehicle, if no accident occurs $P(C_{ADR}|NoACC)$. In order to formulate second unknown term - the probability of correctly labeled vehicle if no accident occurs $P(C_{ADR}|NoACC)$ - it is neccesary to formulate the first term from known values - the probability of occuring accident of correctly labeled vehicle $P(ACC|C_{ADR})$.

The (7) formula shows us the theoretical relation between probability of occuring the ADR accident, determined in the article (7) and probability of occuring an accident of correctly labeled ADR vehicle, which is in formula (6). Difference between those two probabilities, expressed by a k_{kr} coefficient is caused by wrong labelling of ADR vehicles. If ADR vehicles are correctly labeled according to the ADR agreement, the coefficient will equal one and the probability of occuring an accident won´t change.

$$P(ACC|C_{ADR}) = P(ACC).k_{kr} \qquad (7)$$
$$0 < k_{kr} \leq 1$$

In order to achieve safer ADR transportation, it is necessary to minimize the number of incorrectly labeled ADR vehicles, considering both types - intentional or unintentional mistakes.

The maximum variance between probabilities of occuring an ADR accident and of occuring an accident of correctly labeled ADR vehicle will be determined as an expert estimation. The difference will be represented by a coefficient k_{kr}. This is how we set the maximum part of the incorrectly labeled ADR vehicle in occured accidents, which will be considered as acceptable. The (7) formula will be substituted into the (6), from which is the probability of correctly labeled ADR vehicle if no accident occurs determined (8).

$$P(C_{ADR}|NoACC) = \frac{P(C_{ADR}|ACC)}{P(NoACC)}.\left(\frac{1}{k_{kr}} - P(ACC)\right) \qquad (8)$$

4. MATHEMATICAL SOLUTION

In this section we will verify the theoretical solution by numerical calculation of the probability of correctly labeled ADR vehicle $P(C_{ADR}|NoACC)$, which is set in formula (8). Firstly it is necessary to determine the probability of correct labelling of the ADR vehicle, if the accident occurs $P(C_{ADR}|ACC)$. This relation is shown in formula (3), for which we use input values from formula (4). As an input for calculation we use the statistical data about

transport of dangerous goods, which are available from the czech police database. The number of ADR traffic accidents is according to this database equal to 97 (7) $ACC_{ADR} = 97$.

If we compare the difference between the number of reported ADR accidents in all of the regions during last few years, we can state that in approximately 2% of ADR traffic accidents were those where the vehicle was incorrectly labeled so it wasn´t an ADR accident at all. $ACC_{W\_ADR} = 1{,}94$. In 2009 there were 5014 freight accidents (over 3,5 tons) (8) $ACC_{FRE} = 5014$, and the ratio of the ADR transport on the overall freight transport was 3,2% (7). Assuming that only 0,1 % of all freight transport accidents involves vehicles carrying dangerous goods, but aren´t correctly labeled as an ADR vehicle, we get 5 accidents in 2010 $NEH_{CH\_NAK} = 5$. If we use this inputs in formula (4) we get the probability of incorrectly labeled ADR vehicle if an accident occurs $\mathrm{P(W_{ADR}|ACC)} = 0{,}0213$. This result is an input value into the formula (3). Probability of correct labelling of an ADR vehicle, if an accident occurs is $P(C_{ADR}|ACC) = 0{,}9787$.

The theoretical relation between the probability of an ADR accident and the probability of an ADR accident involving the correctly labeled ADR vehicles is in the formula (7). Since that mistakes in labelling occurs, the probability of an ADR accident will be higher than probability of an ADR accident involving the correctly labeled ADR vehicle. Maximum variance between these two probabilities is assessed to 2%, then $k_{kr} = 0{,}98$.

All of the input values for (8) formula are known now. Probability of correctly labeled vehicle according to the ADR agreement is $\mathrm{P(C_{ADR}|NoACC)} = 0{,}998664$. The values of the probabilities are dimensionless numbers. The results could be interpreted that 99,8664% of vehicles carrying dangerous goods are correctly labeled by orange tables.

CONCLUSION

In this article we introduce the calculation of probability of correctly labeled vehicles carrying dangerous goods according to the ADR agreement. As an input for general formulas we use the statistical data from the czech police database. As a result of the calcutation we can state that the probability of correct ADR vehicle labelling is 0,998664. This probability could be considered as very high, but as it was already mentioned in section 2, this probability cannot be interpreted as the probability of correctly labeled vehicle according to all of the requirements of ADR. For purpose of this calculation we consider as a correctly labeled even such vehicles, which are labeled for instance by an insufficient number of orange tables, by tables that are not technologically in order with ADR requirements or even those vehicles which have been labeled with tables with incorrect UN number. These mistakes can also cause consequences, because fire brigade, police and other units which are on the place of accident may not correctly identify the nature of the goods. For this reason we have to pay greater attention to the risks, which are related to the correct interpretation of the result. We can say that only 99,8664 % of ADR vehicles are labeled by "any" orange tables. The rest of the ADR vehicles, which are not labeled, represents serious risks for environment, intervention units, and other people when accident occurs.

In term of correct interpretation of obtained results it is necessary to emphasise, that due to the problematical availability of input data we use more or less estimated values for the mathematical calculation. Despite the fact that we try to maximise the effectivness of

application of theoretical methods, it is possible that the real values could be slightly different. The k_{kr} coefficient, which represents our level of trust that the ADR vehicle was correctly labeled if the accident occus, influences the result very much.

Probability of correct ADR vehicle labelling is very interesting input data for several purposes. For example we can compare our values with other countries and than estimate the level of transport safety in these countries.

It is necessary to focus on the controlling system of this type of transport, in order to reduce the risks which can occurs. This can lead to a reduction of incorrectly labeled vehicles so the probability of correct ADR vehicle labelling $P(C_{ADR}|NoACC)$ approaches number one.

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