Assessment model for the transport of dangerous goods through road tunnels

Mirjam Nelisse and Ton Vrouwenvelder
TNO
Delft, the Netherlands (mirjam.nelisse@tno.nl)

ABSTRACT

In many cases decisions have to be made with respect to the safety level that has to be maintained in tunnels. In this paper the central question is how one can decide between (a) a tunnel with limited allowance for dangerous goods and a deviation route for the prohibited goods or (b) a tunnel allowed for all dangerous goods and possibly equipped with additional safety measures. In principle these type of decisions should be taken, at least partly, by comparing the costs and benefits of the various alternatives. This paper gives an outset of such an approach and discusses the needs for further research.

KEYWORDS: dangerous goods, risk analysis, social cost benefit analysis, transport, road tunnels.

INTRODUCTION

At present, many road tunnels in the Netherlands are not open for the transport of all dangerous goods. The obvious reason is that dangerous good transport may lead to fires and explosions and thus to serious accidents in tunnels, endangering the lives of many people and in extreme cases possibly the integrity of the tunnel structures itself. However, the alternative routes that have to be taken may pose other groups of persons at risk and is an economical loss in itself. So the question arises whether it makes sense to allow free transport in a larger set of tunnels or maybe all.

Current rules and laws are limited to safety and not very well structured to deal adequately with those type of decisions. In the Netherlands there are requirements with respect to internal safety, external safety, structural safety, rescue operations and so on. Those rules have been developed more or less independently from each other and there is no guarantee that they will be consistent in all circumstances. What is needed is an integrated inventory and assessment of risks for a set of feasible alternative solutions.

This paper summarises the set up of such an approach, based on a number of research projects carried out in the last decade [1, 4-7]. The basis of the method is a social cost-benefit analysis (SCBA) over the (remaining) life time of the structure. A simplified case study will be presented to illustrate the ideas.

DISCUSSION OF AVAILABLE ASSESSMENT METHODS AND MODELS

In this section we will discuss three earlier methods developed and used for the assessment of infrastructure: the OEEI, TNO and DARTS methods.

The OEEI model

The OEEI guideline (Research program Economical Effects Infrastructure, in Dutch: Onderzoeksprogramma Economische Effecten Infrastructuur) describes a method for the assessment of large
infrastructure projects, based on the social costs and benefits of the different alternatives [3]. Difference is made into direct effects, indirect effects, external effects and imponderables. Direct effects are directly related to the infrastructure under consideration, e.g. maintenance costs or reduced travel time. Indirect effects are effects on the remainder of the economy, even cross-border effects. For the case at hand these effects are not applicable. External effects are the unintentional and unpriced effects on the common well-being, e.g. environment and safety. That the effects are unpriced does not mean that the consequences are unpriced as well. For example, the unpriced effect of noise nuisance may lead to lower prices of houses. Imponderables are effects that cannot be expressed in money, such as "distribution effects". Distribution effects mean that the effects, positive as well as negative, are not distributed equally between groups of stakeholders, such as users, residents, etc. [1]. The structure and methodology of the OEEI model can be used as a basis for the assessment model.

The TNO assessment model

In the 1980's TNO has developed an assessment model to decide upon the preferred route for the transportation of (classes of) dangerous goods and to assess whether the corresponding risk is acceptable. The model gives insight in the risk in terms of victims and in the economical costs and has been described in [4, 5, 6, 7] and has been, amongst others, applied in [8, 9].

![TNO assessment procedure](image)

Basically the routes and surrounding area up to 250 m from the route are segmented and both the population density and the economical value of the buildings are determined. Most of this information is available after execution of a risk analysis for internal (RWS-QRA [10]) and external (RBMII [11]) safety. However, the TNO risk analysis model additionally indicates the material damage based on scenarios with explosives, flammable gasses, toxic liquids and toxic gasses. The model takes into account the following aspects:

- **Number of victims per year:**
  - Victims on the road/in the tunnel due to traffic incidents with dangerous goods involved;
  - Victims in the surrounding area due to traffic incidents with dangerous goods involved;
  - Victims due to traffic incidents without dangerous goods involved.

- **Economic costs:**
o Material damage due to traffic incidents with dangerous goods involved;
o Material damage due to traffic incidents without dangerous goods involved;
o Additional transport costs associated with the longest of the two alternatives;
o Damage due to transport;
o Economic damage due to irreparable damage to the tunnel.

The results of the calculations are the expected value of the number of victims and the economic costs for every alternative. The expected value for large incidents is calculated separately, to include risk aversion. It is also possible to include a factor representing the acceptable value to prevent one victim. The analysis concludes with a sensitivity analysis, to get insight into the robustness of the preferred alternative.

The principle of the model is suitable as basis for the new assessment model. It focuses on the risks resulting directly from the alternatives, but does not include indirect or external effects, such as damage to the environment. An advantage is that risk aversion is included. A disadvantage is that the risk analysis is somewhat out-of-date and needs updating. The weighing method however can certainly be applied.

**The DARTS model**

Within the European Research project “Durable And Reliable Tunnel Structures (DARTS), a comprehensive decision tool has been developed [12]. The model is quite alike the OEEI model, but focuses on the attribution of costs to certain stages of development of the tunnel (design, construction, etc.) and on the detailed composition of the costs. The methods for the determination of costs are usually qualitative. The environmental effects have been subdivided in 11 aspects, which is too detailed for the case at hand, and will therefore not be treated here. For the assessment of the costs of the environmental aspects, several methods are supplied, such as:

- Contingent valuation method: the “willingness to pay” for a specific environmental issue or the compensation needed to counteract that effect;
- Travel costs method: the “willingness to pay” to travel to and through the nature to enjoy it;
- Hedonic price method: a method based on the difference in price between goods with or without the environmental effects (e.g. same house, with or without noise nuisance).

The DARTS model focuses on risks during construction, which is not relevant for the case at hand. Furthermore, additional (OECD) scenarios are taken into account, which are not applicable for this case as well. However, the principle of this method can be used as a basis for the new assessment model.

**PROPOSED MODEL**

Based on the study of the three assessment procedures we may distinguish four main steps [1]:

1. **A system description**

The first step is to describe the system characteristics of both the tunnel and the deviation route. These characteristics may be:

- Type of transport of dangerous goods (allowed categories);
- Tunnel system: lay-out, structure and installations;
- Safety measures: preventing as well as mitigating measures;
- Procedures;
- Emergency services;
- Education and training;
• Length of the deviation route vs. length of the tunnel;
• Road type(s) of the deviation route;
• Surrounding area: industrial area, residential area, etc..

2.  **Formulation of alternatives**

For the case of the transport restrictions for dangerous goods the **basic** alternative is the current situation: a tunnel with limited allowance of dangerous goods transport and a deviation route for the transport of the dangerous goods that are not allowed through the tunnel. Most tunnels in the Netherlands, 21 out of 25, are currently ADR 2011 category C or D [13]. Category C poses limitations on dangerous goods that can cause a very large explosion, a large explosion or the release of a large quantity of toxic substances. In addition to category C, category D poses also limitations to dangerous goods that can cause a large fire.

The **second** alternative, the alternative that will be compared to the basic alternative is in first instance the situation where all dangerous goods transport takes place through the tunnel and the deviation route is not longer used for dangerous goods transport. In that way the tunnel under consideration becomes a category A tunnel: no limitations to the transport of dangerous goods.

After the first comparison it may turn out that the second alternative does not perform according to the minimum requirements for internal, external or structural safety. Then a third or even more alternatives may be introduced. These alternatives are as alternative two, but with a package of (safety) measures added to perform according to the requirements. The optimization of the package of measures is an iterative process.

3.  **Evaluation of relevant costs and benefits**

The costs to be evaluated are presented in the list below. Benefits are included as costs with a negative value.

1) Financial costs
2) Traffic related costs
3) Risk related costs
4) Environmental costs (pollution, emission, noise, etc))
5) Interests of stakeholders/Distribution-effects
6) Risk perception

For the first three items a further subdivision into various items has been presented in the tables 1 to 3. Items 4 to 6 have not been further developed in this paper. The interested reader is referred to [1] and [12].

An interesting point of course is the way the loss of human lives is taken care of in a Social Cost Benefit Analysis. In this study we will consider a two step procedure. Based on [15, 16] a “value” for a casualty of 2 million Euro is considered in the economic calculation. Secondly it is required that the loss of human lives fulfils the requirements following from internal and external safety criteria, in principle both for Individual and Social Risk. In some countries, like for instance the Netherlands, those criteria may even be part of the law.

4.  **Comparison**

In the last step the various alternatives are compared and a decision is taken. A possible decision might be to develop and consider a number of other promising alternatives.
**Table 1: Financial costs**

<table>
<thead>
<tr>
<th>Construction</th>
<th>Basic costs of construction and standard package of safety measures.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Costs involved with labour, energy, cleaning, etc. Differences in costs will occur due to differences in safety measures.</td>
</tr>
<tr>
<td>Maintenance and repair</td>
<td>Inspection, maintenance and repair of the construction and the installations of the tunnel.</td>
</tr>
<tr>
<td>Additional measures</td>
<td>Costs for technical as well as organizational measures (e.g. training and education of emergency services).</td>
</tr>
</tbody>
</table>

**Table 2: Traffic related cost**

<table>
<thead>
<tr>
<th>Detour</th>
<th>The costs of driving via the deviation route consists of the fuel, maintenance and debit of the vehicles.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td>The travel time costs consist of the (difference in) time that it costs to take the deviation route or the shorter route through the tunnel, expressed in money. The time gained is dependent of the difference in the length of the route, the speed (limit) and traffic build-up.</td>
</tr>
<tr>
<td>Additional measures for trucks</td>
<td>These costs concern measures at the source of unsafety, the trucks, such as reinforced tanks, compartmentalization and coating. The benefits of these measures not only benefit the safety of the tunnel, but also the remainder of the transportation route. The costs therefore need to be attributed by kilometre for example. One could choose to multiply the costs per kilometre with a weighing factor for tunnels, since they usually benefit more than the open road.</td>
</tr>
<tr>
<td>Enforcement</td>
<td>Currently certain types of dangerous goods are not allowed through the tunnel. This ban needs to be enforced, for example by the police. Furthermore the trucks may be controlled on the deviation route for not complying with the speed limits. Allowance of dangerous goods makes enforcement less or unnecessary.</td>
</tr>
</tbody>
</table>

**Table 3: Risk related costs**

| Internal risk | The internal risk needs to comply with the current rules and regulations regarding tunnel safety. In the current draft of the new Dutch law the limit for group risk is posed on 0,1/N² per kilometre per year. |
| External risk (tunnel) | The external risk, the risk of victims in the neighbourhood of the tunnel as a result of an accident in the tunnel, should comply with the current rules and regulations. |
| External risk (deviation route) | The external risk should comply with current rules and regulations. The expected value of the number of victims will be generated according to CPR14 and CPR 18 with RMBII or risk curves. |
| Material damage | These are the costs involved as a result of traffic accidents, such as damage to vehicles. |
| Structural damage | Repair or reconstruction of the tunnel or of buildings in the neighbourhood of the deviation route as a consequence of an accident. |
| Medical costs for injured people | Medical care of injured people is usually twice the costs involved with deceased people. The number of injured people is usually much higher than the number of deceased persons. |
| Economical damage after closure of the tunnel | The costs related to unavailability and limited accessibility as a consequence of a closed tunnel for repair or reconstruction due to an accident in the tunnel. The costs are largely dependent of available alternative routes. |
CASE STUDY

In this paragraph a case study is presented according to the steps of the assessment model presented above. It is a simplified version of the example in [1]. The calculations for this case study are based on the combination of the existing risk analyses. The order of magnitude of the output is realistic, but some of the results may be less logical or less fitting, due to the combination of methods. Furthermore some of the numbers are estimated, because no acceptable basis existed. Discounting future costs to the present has not been done for the sake of a clear example.

1. System description

The tunnel has a length of 2.4 km and consists of two tubes with two lanes. The safety measures are the standard measures.

Per day 77000 vehicles pass the tunnel, of which 37% trucks. About 3% of the trucks transport dangerous goods and only 3.7% of those trucks transport goods (compressed gas and so on) that are not allowed to pass the tunnel. So every day $0.37 \times 0.03 \times 0.037 \times 77000 = 0.0004 \times 77000 = 32$ vehicles per day or about 11500 vehicles per year need to make a detour. The detour is 15 km.

2. Alternatives

The basic alternative consists of a category C tunnel where dangerous goods involving gas or highly flammable materials are prohibited. The second alternative is a category A tunnel where all traffic is allowed but with no additional measures taken.

3. Relevant aspects

Only traffic and risk related costs will be considered in this example. Other costs are either the same for both alternatives or have a negligible influence. Costs are calculated for a period $T = 50 \text{ a}$, say the anticipated lifetime of the structure. For simplicity no discounting is performed.

Traffic related costs

a. Detour

The fuel costs are estimated to be 0.19 €/km and 0.05 €/km for maintenance and depreciation. Given a deviation route of 15 km and a yearly average of 11500 vehicles, the costs are 2.1 Million Euro during the lifetime of the tunnel.

b. Travel time

UNITE [14] states the value of travel time for a heavy goods vehicle (HGV) to be 43 €/hour. Based on the type of roads and their length and average speed of the deviation route, an average travel time of 15 minutes has been estimated. This brings the travel time benefits over the lifetime of the tunnel on 6.2 million Euro.

Risk related costs

The average number $N$ of serious accidents leading to explosions or big fires during the life time $T$ if all traffic is allowed in the tunnel will be in the order of magnitude of

$$ N = \lambda nLT $$

(1)

Where $\lambda$ is the probability that a serious accident leading to fire or an explosion will occur per driven vehicle kilometre in mixed traffic, $n$ is the traffic intensity, $L$ the length of the tunnel and $T$ the period under consideration, in our case the design life time. Taking:
\[ \lambda = 5 \times 10^{-11} \text{ (veh.km)}^{-1}, n = 77,000 \text{ veh/day}, L = 2.4 \text{ km and } T = 50 \text{ a} \]

We arrive at:

\[ N = 5 \times 10^{-11} \times (77000 \times 365) \times 2.4 \times 50 = 0.17 \]

One might also say that the probability of having a serious accident in the tunnel is 17%.

Once an accident with trucks containing atmospheric or pressured gas has occurred, various scenarios may develop. In principle there may be just a fire, a gas explosion, or a cold or a warm BLEVE. Pressures on tunnel elements and consequently resulting damages may vary, depending on a large set of details. In [1] the likelihoods and consequences for a number of these scenarios have been investigated. The result has been summarised in Table 4. It has been assumed that the tunnel will collapse partly at explosion pressures above 250 kPa and that full collapse may occur at BLEVE pressures higher than 450 kPa.

Table 4: Risk calculation given a fire accident

<table>
<thead>
<tr>
<th>Event</th>
<th>Conditional Probability</th>
<th>Damage class</th>
<th>Damage [M€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire (large)</td>
<td>0.46</td>
<td>Small</td>
<td>3</td>
</tr>
<tr>
<td>Explosion &lt;250 kPa</td>
<td>0.04</td>
<td>Small</td>
<td>3</td>
</tr>
<tr>
<td>Explosion &gt;250 kPa</td>
<td>0.10</td>
<td>Medium</td>
<td>25</td>
</tr>
<tr>
<td>BLEVE &lt;450 kPa</td>
<td>0.05</td>
<td>Medium</td>
<td>25</td>
</tr>
<tr>
<td>BLEVE &gt;450 kPa</td>
<td>0.35</td>
<td>Large</td>
<td>255</td>
</tr>
</tbody>
</table>

Calculating the products of probabilities and damages and adding them we arrive at an expected damage \( E_D \) of 95 M€. Multiplying with the expected number of serious events \( N=0.17 \) we arrive at a risk of

\[ \text{Life time Risk} = N E_D = 0.17 \times 95 = 16 \text{ M€} \] (2)

The number of casualties can be calculated in a similar way. For the basic alternative one should also calculate the number of casualties caused by the 15 km detouring dangerous good transports. In this example a net number of 2 additional live losses resulted [1].

4. Comparison

The economic gain of having less detours is (rounded off) 8 Million Euro while the loss due to the extra risk is 16 million Euro. In addition there is an expected additional loss of lives, which will increase the 16 to 20 million Euro if the 2 M€-value mentioned before is adopted.

The conclusion is that in this case the tunnel should not be set open to all types of traffic. Of course this might be different if for instance the detour would have been larger or if additional measures could be taken without too much effort. In [1] this has been elaborated to some extent.

CONCLUSIONS AND RECOMMENDATIONS

The assessment model as presented in this paper has been based on the structure of the OEEI guideline and the components of the TNO, the DARTS and the RWS-QRA models. The systematic approach seems to be feasible for facilitating decisions regarding the allowance of all dangerous goods through tunnels. However, the assessment model is an outset that needs to be further developed, for example by means of case studies.
In the outset for the assessment model, the following knowledge gaps have been identified:

1. The current outset for the assessment model does not include the option of weighing factors. It should be possible to incorporate weighing factors in the model. Furthermore the quantification of the weighing factors, which is dependent of the stakeholders as well, should be determined.
2. The structural damage as a result of the scenarios that are identified in the RWS-QRA model, cannot yet be quantified. Especially the structural damage as a result of explosions, but also as a result of toxic substances, is an important knowledge gap. The costs involved with structural damage, for example for repair or as a result of collapse of the tunnel, are unknown.
3. The current RWS-QRA model only quantifies victims, but not injured people. Quantification of the number of injured people is important for the further development of the assessment model.
4. The current RWS-QRA model does not include explosion scenarios in a proper way and needs to be improved.
5. If safety measures need to be taken, these can be applied to either the tunnel or the trucks. At the moment it is not possible to quantify the (part of the) costs that are involved with the application of safety measures to trucks.

It is important that procedures and methods are developed further in order to reduce the degree of arbitrariness and inconsistency in choosing between alternatives. This does not only hold for the closure of vehicles for certain type of transports but equally for all other type of safety related decisions.

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