QUANTITATIVE RISK ANALYSIS OF AMMUNITION TRANSSHIPMENT IN HARBORS
H.P.A. Dijkers and P.A. Hooijmeijer
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TRANSSHIPMENT IN PRACTICE
SOURCE OF RISK

- Ammunition transshipments are a source of risk to the surrounding area and the people nearby (involved in the transshipment or third parties)
- In a harbor generally large volumes and quantities of ammunition and explosives are transshipped, so the expected effects of an explosion are significant (reaching up to several kilometres)
- The Dutch MoD tasked TNO to develop a method to quantify the risk associated with ammunition transshipments, so an informed decision can be made if the level of risk is acceptable. If not:
  - Possible risk mitigation measures
  - Different harbor to perform transshipment(s)
- This presentation gives an overview of the method to perform a quantitative risk analysis of ammunition transshipments in harbors
MAIN CAUSES OF ACCIDENTS

- Crane operations (hoisting of containers)
- Fire on ship or truck
- Accident with vehicles
METHOD FOR RISK ANALYSIS

› Quantitative risk analysis (QRA):
  1. Scenario’s for transhipments
  2. Estimation of probability of accidental explosion
  3. Calculation of effects of accidental explosion
  4. Calculation of consequences (lethality) of accidental explosion
  5. Calculation of risks (consequences x probability)
  6. Assessment according to national norms

› QRA performed with TNO Transhipment Tool:
  › Developed especially for this purpose, risk analysis of ammunition transhipments
For a specific harbor a set of scenarios is defined, this set contains all transshipments that are planned to be performed in that particular harbor in a single year.

A scenario defines:
- Total amount of explosives and ammunition to be transshipped:
  - NEQ in kg TNT
  - Hazard Division: HD 1.1 is assumed for all ammunition, except HD 1.4 articles
- Number of transshipments of a certain NEQ per year
- Number of ISO-containers per transshipment of a certain NEQ
- Number of kilometers travelled by vehicles in a transshipment of a certain NEQ
- Type of ship involved (CONRO, RORO, etc.)
- Amount of time needed for a transshipment
PROBABILITY OF AN EXPLOSION

- Based on parameters for each scenario, probability of explosion is determined using:
  \[ P_{\text{expl}} = 2 \cdot \sum P_{\text{event}} \cdot N_{\text{event}} \cdot P_{\text{expl, event}} \]

- For several types of accidents, based on historic data, frequencies and probability of explosion are estimated:

<table>
<thead>
<tr>
<th>Event, unit</th>
<th>Event frequency / unit</th>
<th>Probability of explosion / event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire in a vehicle, km</td>
<td>5.0 \cdot 10^{-9} / km</td>
<td>1.0</td>
</tr>
<tr>
<td>Accident or collision with a vehicle, km</td>
<td>1.0 \cdot 10^{-7} / km</td>
<td>0.001</td>
</tr>
<tr>
<td>Fire aboard a CONRO/general cargo, # of ships</td>
<td>1.0 \cdot 10^{-6} / ship</td>
<td>1.0</td>
</tr>
<tr>
<td>Fire aboard a container ship, # of ships</td>
<td>2.0 \cdot 10^{-8} / ship</td>
<td>1.0</td>
</tr>
<tr>
<td>Crane accident with container, # of crane moves</td>
<td>2.0 \cdot 10^{-6} / move</td>
<td>0.011</td>
</tr>
</tbody>
</table>

- Cumulated to get total probability of explosion for specific scenario
NEQ PER TRANSSHIPMENT

- To help establish how many transhipments with a certain NEQ need to be planned in a particular port, historic data can be used.
- Cumulative (relative) distribution can provide insight.

Cumulative distribution of the NEQ NL ammunition transshipments. Based on data from the Dutch Ministry of Defence from the period 2002-2015.
EFFECTS OF AN EXPLOSION

- The following physical effects of an accidental explosion are calculated:
  - Peak pressure of the blast wave
  - Peak impulse of the blast wave
  - Duration of positive phase of the blast wave
  - Fragment and debris distribution
  - Heat radiation (HD 1.3)
CONSEQUENCES (LETHALITY)

The determined explosion effects are related to a probability of lethality using Probit relations:

\[ Pr = A + B \cdot \ln X \]

Probit relation either valid for people in the open field or inside a building:

<table>
<thead>
<tr>
<th>In the open field</th>
<th>Inside buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fragments</td>
<td>• Fragments</td>
</tr>
<tr>
<td>• Debris</td>
<td>• Debris</td>
</tr>
<tr>
<td>• Blast:</td>
<td>• Combination of factors (model of Gilbert, Lees and Scilly*):</td>
</tr>
<tr>
<td>• Lung injury</td>
<td>• Building collapse</td>
</tr>
<tr>
<td>• Collision of head</td>
<td>• Window breakage</td>
</tr>
<tr>
<td>• Collision of body</td>
<td>• Blast</td>
</tr>
<tr>
<td>• Heat</td>
<td>• Etc.</td>
</tr>
</tbody>
</table>

* = Gilbert S.M., Lees F.P. and Scilly N.F., A model hazard assessment of the explosion of an explosives vehicle in a built-up area, 1994
QUANTITATIVE RISK ANALYSIS (1)

Main focus on third party risk, two common concepts to describe this:

A. Individual risk (IR):
   - All transshipments that are planned to be performed in a particular harbor in a single year are considered
   - Does not take into account any buildings
   - Assumes permanent presence of persons in the area of interest
   - For scenarios 1 to $n$: $IR(r) = \sum_{i=1}^{n} P_{\text{expl},i} \cdot P_{\text{lethal}}(NEQ_i, r) \cdot N_i$
     - $P_{\text{expl},i}$: probability of explosion
     - $P_{\text{lethal}}$: probability of lethality for a certain location
     - $N_i$: the number of transshipments per year of scenario $i$
B. Societal risk or Group risk (GR):

- All transshipments that are planned to be performed in a particular harbor in a single year are considered.
- Accounts for actual presence of people in surrounding area and presence of buildings.
  - Only within area of influence: area within ‘Inhabited Buidling Distance’ (IBD), obtained from AASTP-1, with an ISO-container as PES.
- A lot of work to gather data:
  - Amount of people present in houses, factories, offices etc.
  - Many parties involved (companies, municipalities, etc.)
- Presented in cumulative F(N) curve, expressing cumulative frequency per year that N or more fatalities can occur.
ACTUAL CASE

- Case calculated for NL MoD
- Scenario’s based planned transhipments for coming years (estimate)
- Risk analysis results:
  - Individual Risk
  - Group Risk
ACTUAL CASE: INDIVIDUAL RISK

- In NL $1 \cdot 10^{-6}$/year is an important limit value for IR
- Inhabited buildings inside this contour are considered an infringement
- Contributions of all scenario’s cumulated
- Local and national government decide on acceptance of risk
Each blue dot represents a number of identical transhipments grouped in one scenario.

Blue curve represents the cumulated contributions of all scenarios.

Local and National government decide on acceptance of risk.
POSSIBLE FUTURE DEVELOPMENTS

- Improve debris and ballistic flight condition models for ISO-containers:
  - Axisymmetric debris throw by ISO-containers is very crude assumption
  - Klotz Group research can be used as basis

- Below decks placement of ammunition containers:
  - Research on influence of ship structure on explosion effects
  - Debris and fragment throw, and blast propagation affected by ship structure

- Efforts to develop better/alternative methods to determine probability of explosion:
  - Now, scarcity of data (fortunately), estimated uncertainty up to a factor of 2
THANK YOU FOR YOUR ATTENTION

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