PROBABILITY ASPECTS OF THE INITIATION OF AMMUNITION AND EXPLOSIVES

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MSIAC UNCLASSIFIED
Contents

- Munitions Safety Information Analysis Center (MSIAC)

- Introduction

- Fault trees and probabilistic analysis

- Case study 1: Shock induced Detonation

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- Conclusions
History of NIMIC/MSIAC is linked to history of IM

- Need arose from horrific accidents of 1960 and 1970s
Technical Information & Analysis Center Focusing on Munitions Safety

- NATO Project Office
- Independently Funded by its Member Nations

MSIAC Strategic Goal:

*Eliminate Hazardous Consequences due to Unintended Reactions of Munitions and Energetic Materials Throughout their Lifecycle*
MSIAC Governance

- MSIAC Strategies, Policies, & Work Efforts Defined by a Steering Committee (SC)
  - 1 SC Representative per Member Nation, 1 Vote per Member Nation
  - 1 Elected Chairman (non-voting) from a Member Nation

- 13 Members

- Poland is in the process of joining

- ROK joining in 2017
Supporting Munitions Safety

- More than 20 Workshops
- Open- and Limited-Distribution Reports
- Support NATO Policy, Advice and Review
- Open & Secure Websites with more than 600 users
- Answering more than 2600 Technical Questions
- Training, Country visits, Fellow and Students
- 15 Distributable Software Tools and Databases
MSIAC Drivers

- Want to minimise the risk from our own munitions
- Understand and demonstrate benefits of munitions safety throughout the lifecycle
- Improve and standardise munitions safety risk assessment methodologies
- Harmonize munitions safety policies to achieve greater sharing of munitions safety evidence
- Standardise approach to safe storage and use of munitions in operational theatres
- Access to world leading scientific and technical analysis, and advice to support decisions on munitions safety and risk management
NATO Policy

- MSIAC support: Experimental and theoretical basis of current NATO standards for safe storage of ammunition
NATO Policy

Hazard Classification

AASTP-3

Guidelines for safe storage of ammunition

AASTP-1

Home country: Quantity Distances (QD)

AASTP-5

Deployed operations: Field Distances (FD)

If these cannot be met:

Explosives Safety Risk Analysis

AASTP-4

Detailed models

Explosives Safety and Munitions Risk Management (ESMRM)

ALP-16

Risk Tracking

Risk Analysis

Risk Approval

Risk Control Plan

Continuous process
To be conducted by ESO
As Low As Reasonably Practicable (ALARP)
Level of authority for risk approval
Introduction

- Risk of accidental initiation of ammunition and explosives
  - Risk = Frequency * Consequence * Exposure
  - Qualitative and Quantitative methods

- Quantitative Risk Analysis (QRA)
  - Exploits scientific knowledge on explosion effects and consequences
  - Less subjectivity compared to qualitative approaches
  - To be compared with (national) acceptance criteria for Individual Risk (IR) and Group Risk (GR)
A new approach for quantifying frequency of events through historical methods.

- Quantification of frequency through historical method.
- Leads to generic values, e.g., $10^{-5}$/year.
- Does not recognize benefits of Insensitive Munitions (IM) or mitigation measures.

**Frequency of event** (1/year) as a function of the NEQ for various magazine types.
More realistic approach:

- Fault tree analysis
- Address specific details (threat, explosive, response)
- Address uncertainty (aleatory and epistemic)
- Methods for probabilistic/uncertainty analysis:
  - Linearization
  - Monte Carlo simulation
  - Bayesian Belief Network (BBN)

- BBN has been selected to perform two case studies (Agenarisk software)
- Impact distance as a function of
  - Initial velocity
  - Launch angle
  - Ballistic coefficient
- “propagation” of uncertainty through network
Case study 1: Detonation

- Shock induced detonation prediction with Jacobs Roslund model (included in MSIAC tool “Temper”)

- Input:
  - Target explosive
  - Target cover thickness (t)
  - Fragment shape (flat, hemisphere)
  - Fragment critical dimension (d)
  - Fragment impact velocity (V)

- Output
  - Critical impact velocity for detonation \((V_c)\)
  - Detonation likely or not?

\[
V_c = \left(\frac{A}{d^{1/2}}\right)(1 + B)(1 + C/d)
\]
Case study 1: Detonation

- Empirical basis of Jacobs Roslund model

Rowanex-1001 covered by aluminium and impacted by a Flat-Ended Fragment (D=13.15 mm and 20 mm)
Case study 1: Detonation

- Constants A, B and C

<table>
<thead>
<tr>
<th>Explosive Type</th>
<th>Density (g/cm³)</th>
<th>A (mm²/°C)</th>
<th>B (Hemispherical Frag)</th>
<th>C (Flat Frag)</th>
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<td>0.906</td>
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</table>

- Deterministic analysis with conservative assumptions:
  - Minimum cover thickness (0.36 in = 9 mm)
  - Worst case fragment shape (flat)
  - 95% confidence fragment mass (e.g. 50 g)
  - Maximum impact velocity (e.g. 2000 m/s)

- Result:
  - Critical velocity ~ 1600 m/s
  - This means “Detonation”
Case study 1: Detonation

- **Probabilistic analysis** takes into account realistic variations
  - Cover thickness: 9 to 17 mm
  - Threat fragment mass and velocity distribution
  - Flat and hemispherical fragment shapes
  - Explosive set to “Comp B” as an “observation”

Result:
- Detonation: 36%
- No Detonation: 64%
Case study 1: Detonation

- Possible extensions of this case study:
  
  - Determine fragment mass and velocity distribution based on:
    - Threat properties (e.g. mortar, artillery)
    - Distance from threat to target (air drag)
    - Protection between threat and target
      (e.g. penetration of ISO container wall and residual velocity)
  
  - Determine Jacobs Roslund parameters for insensitive explosives
    - Correlation with gap tests
  
  - Add influence of fragment impact angle and orientation (yaw)
  
  - Correct treatment of multiple hit
Supporting Munitions Safety

Case study 2: Blast IBD

- Potential Explosion Site (PES) licensed with 10,000 kg HD1.1
- Inhabited Building Distance (IBD)
  \[ IBD = 22.2 \cdot NEQ^{\frac{1}{3}} = 478\text{m} \]

- Planned office buildings at 360 m and beyond violate IBD
Probabilistic analysis takes into account variations in:

- Filling level of magazine in the course of one year
  - 0.5 to 1

- TNT equivalence of stored ammunition
  - 0.7 to 1.3

- Fraction of NEQ that (contributes to) detonation
  - 0.3 to 1

- Distribution of personnel over area with new office buildings
  - From 360 m to 600 m (peaks around 478 m)

- Note: Licensed NEQ is a fixed value entered as an observation
Case study 2: Blast IBD

- Result: only in 6% of initiation events there will be a violation of the IBD criterion
Possible extensions of this case study

- More complex QD (blast AND debris based)
- Include the distribution of exposure and presence of people (day/night)
- Add real data on filling level of a magazine
- Add reliable predictions of fraction of NEQ that detonates
Conclusions

- Positive experience with Bayesian Belief Networks (BBN)

- Probabilistic analysis
  - gives a more realistic picture than a deterministic (conservative) approach
  - enables more accurate event frequency and risk analysis

- Challenges
  - To quantify the input distributions
  - Not to miss black swan events
Conclusions

- Case studies triggered new research topics:
  - Availability of parameters for shock induced detonation of IM
  - Realistic ammunition magazine filling level distributions
  - Realistic fractions of a HD1.1 stack that will detonate
Future work

- Promote the use of probabilistic techniques
  - International symposia and NATO working groups
  - Information exchange with MSIAC members

- Conduct more case studies, e.g.
  - Dropping of explosives
  - Blast loading of buildings
  - Insensitive Munitions
  - Range Safety

Variations in impact distance caused by variations in initial velocity, launch angle, and ballistic resistance
Questions

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This workshop seeks to exploit our improved understanding of munitions vulnerability and consequences to deliver improvements in munitions risk management.

10-14 September 2018, Location TBD