Risk model for large-scale munition transshipments in seaports

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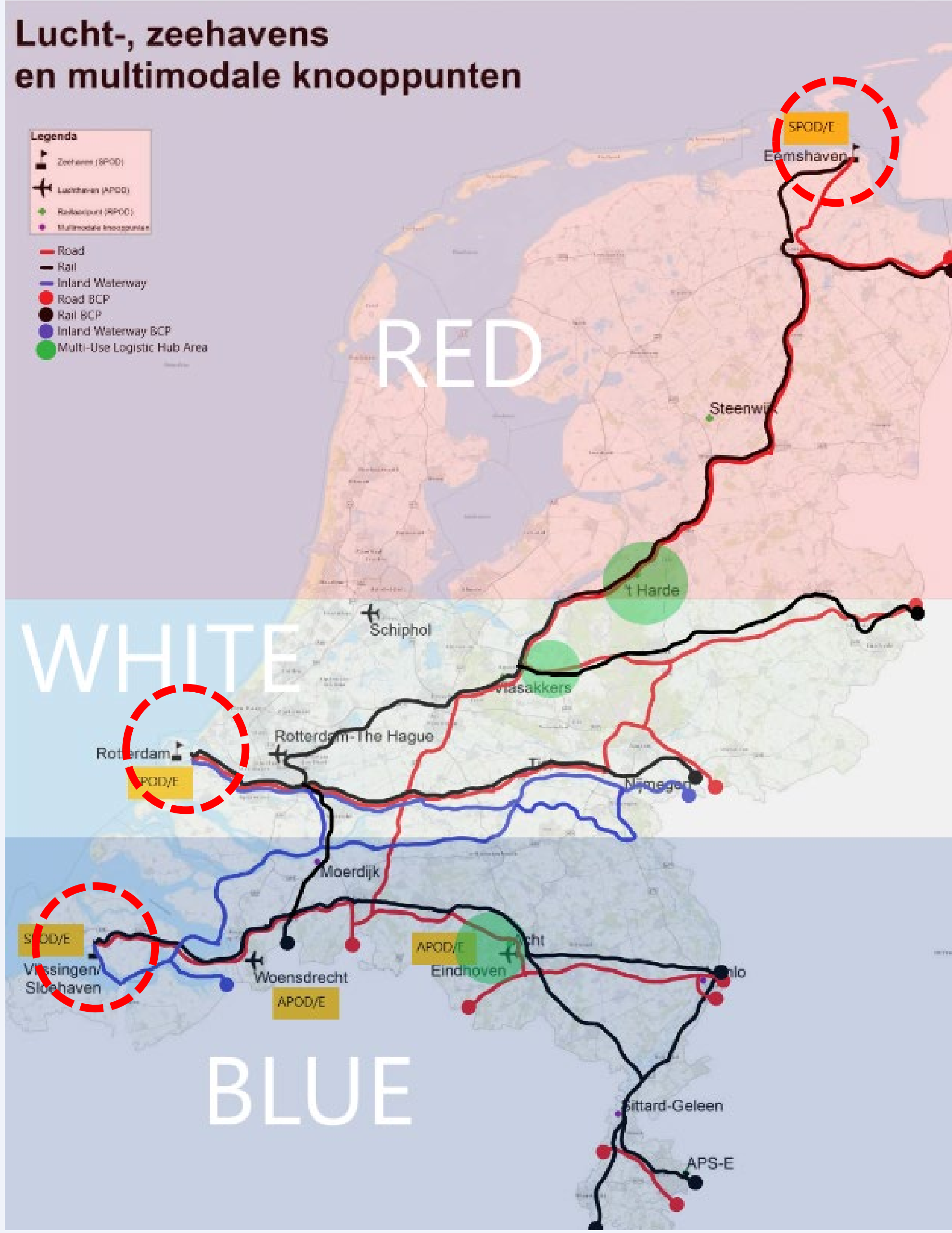
The Netherlands as Host Nation

NL facilitates Host Nation Support (HNS) operations within the NATO alliance

- Strategically located in Western Europe, so transit country for **munitions**, military equipment and/or troops
- Three multimodal corridors which start in seaports

Transhipment of large quantities of munitions takes place in seaports

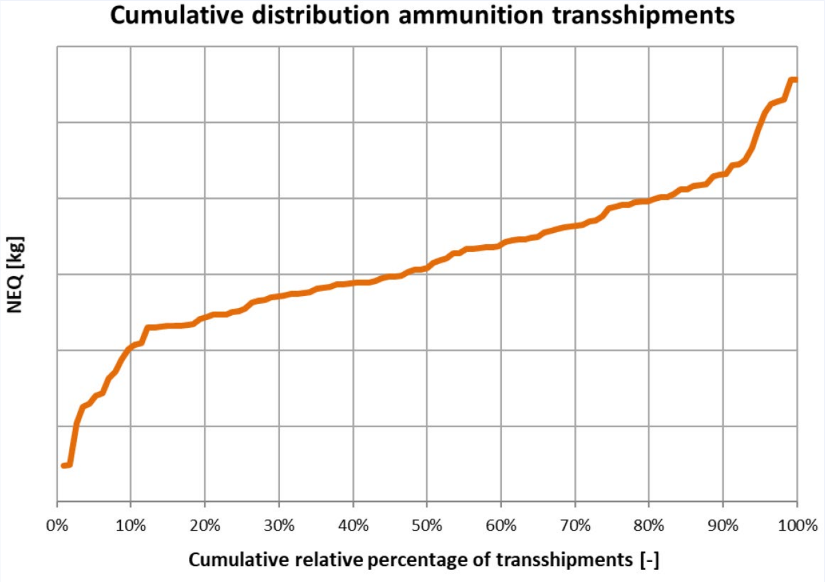
- NL MoD/TNO are exploring conditions to facilitate these transhipment activities safely
- Space is limited, so it needs to be ensured that:
  - Handling of munitions is coordinated with other activities in the area
  - Risk remains below acceptance criteria



Background work TNO

- TNO has been developing a **risk methodology (QRA)** to assess the risk posed by large-scale munition transhipments to the surroundings
- This methodology is currently used to determine which locations (and under what conditions) are suitable for planned transhipments
- The following risk parameters are determined and assessed:

1. **Location-specific individual risk**
2. **Group risk**
3. **Risk of domino reactions**
4. **Financial risk**



IESSE 2018

Quantitative Risk analysis of ammunition transshipments in harbors

H.P.A. Dijkers; TNO; Rijswijk; The Netherlands.

P.A. Hooijmeijer; TNO; Rijswijk; The Netherlands.

Keywords: Risk analysis, ammunition, transshipment, harbor, QRA, ship.

Abstract

Ammunition transshipments are a key part of the logistical operations of the armed forces and are often executed via ships. These transshipments pose a risk to the people present in the area surrounding the harbor, where the loading/unloading of the ship takes place. A method is presented to perform a quantitative risk assessment of such ammunition transshipments, where a scenario based approach is used. Engineering models are used to calculate the possible explosion effects (blast, debris/fragments and heat radiation) and Probit relations are used to determine the probability of lethality for unprotected persons. Two well-known concepts to describe third party risk are used to show a practical example of the risk analysis method. With this quantitative method an assessment can be made if the planned ammunition transshipments do not create too great a risk for the people in the area surrounding a particular harbor.

Effect -based vs. Risk -based approach

Effect-based approach reduces the overall expected effects resulting from an accidental explosion

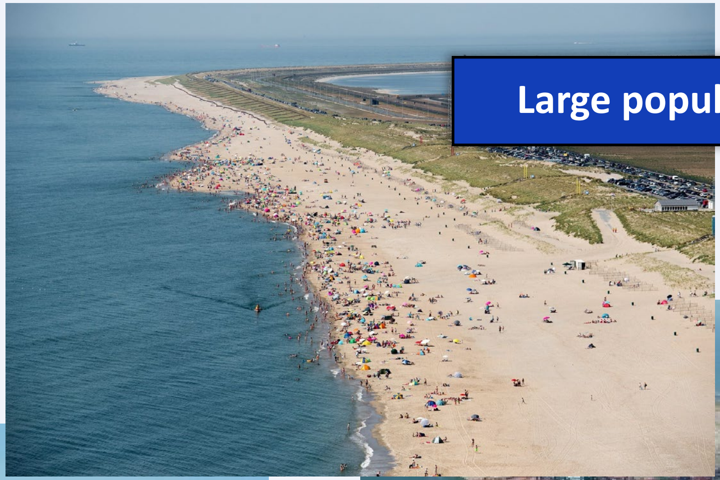
- Storage sites are designed to adhere to established separation distances (e.g. IMD from AASTP-1)
- Munitions are assumed to be always present

Risk-based approach considers the effects and probability of accidental explosions

- Due to storage constraints on ship and trains, separation distances between ISO containers cannot be met
  - Large quantity of inseparable munitions whose effects cannot be reduced in case of an accident
- Munitions are only temporarily present on the ship

Seaports as complex environments

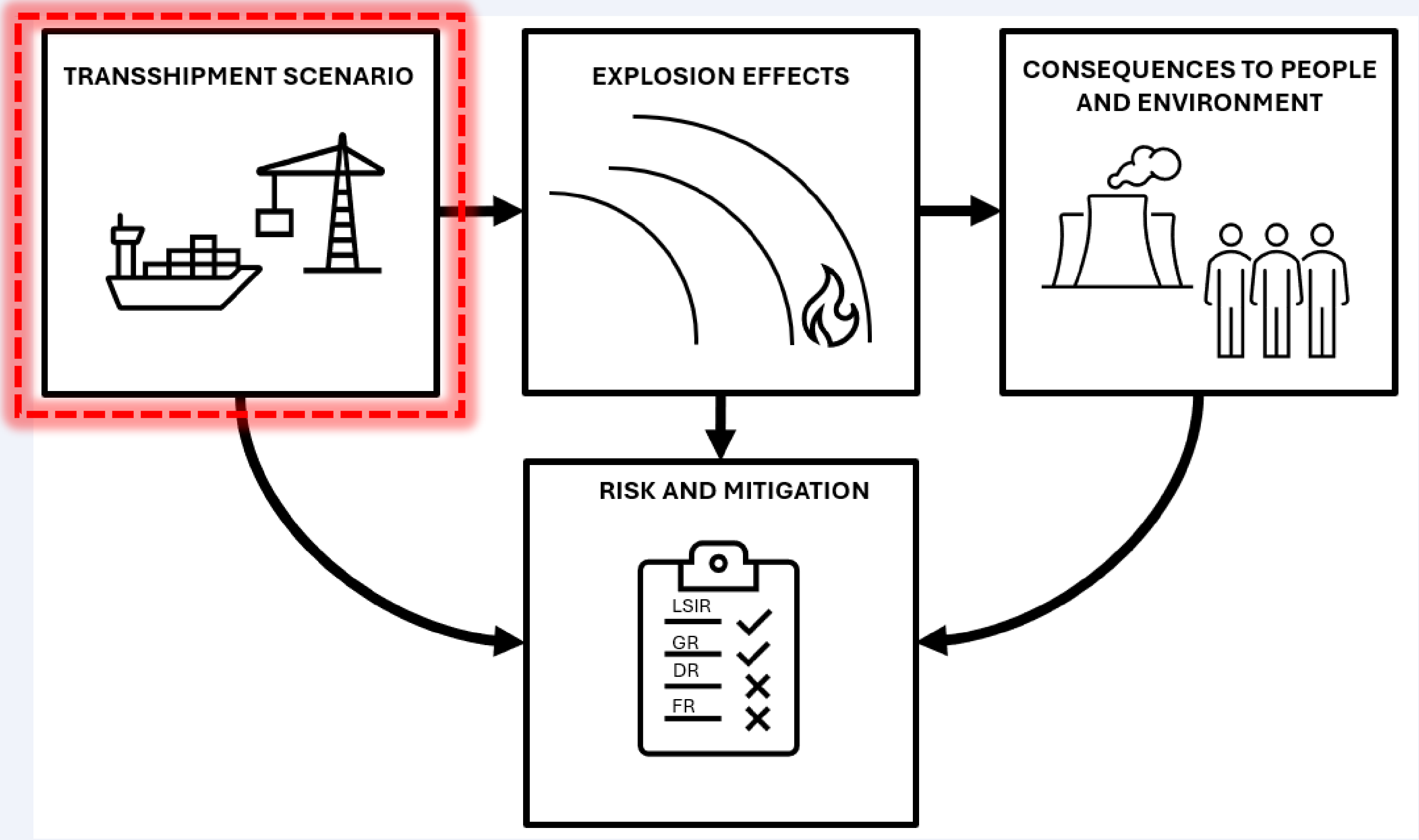
Process industry



Large populations

Critical infrastructure

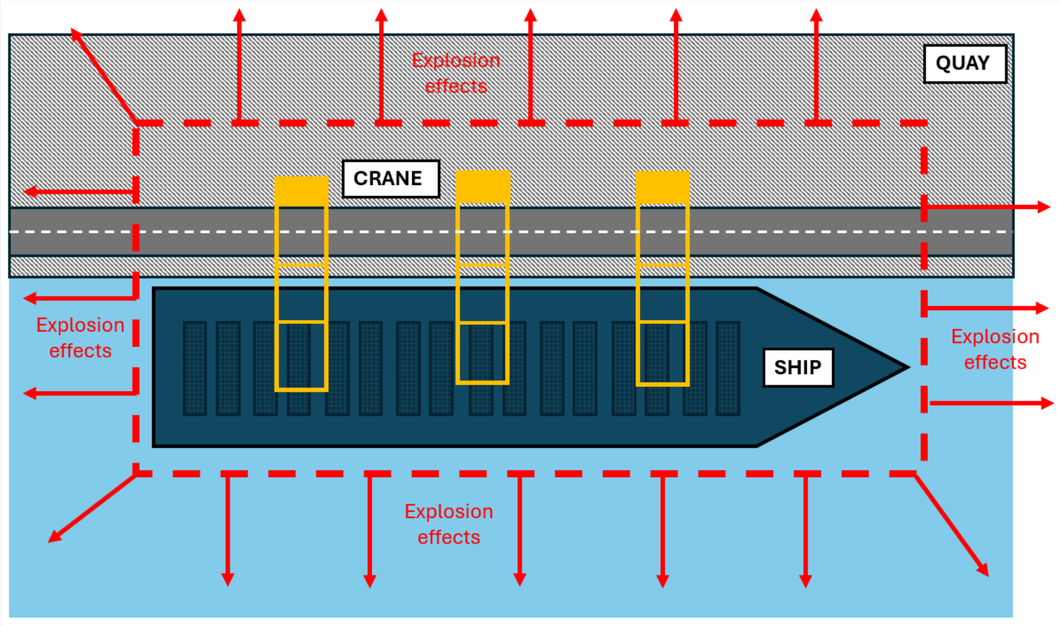
Overview of the risk model



Transhipment scenarios

Three key aspects define the transhipment scenario:

1. **Location of the potential explosion site (PES)**
   - Taken as the area where all ship-to-shore activities take place
   - Explosion effects are projected to the surrounding area from the borders of this area
2. **Net explosive quantity (NEQ)**
   - Maximum credible event (MCE) is equal to aggregated NEQ of all munitions present
   - All munitions are treated as HD1.1, except for HD1.4
3. **Probability of an accidental explosion**
   - Logistic process used for transhipment
   - TNO Transhipment Tool



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Transhipment scenarios

Probability of explosion

- Possible base accidents are mapped out based on each mode in the transhipment process, along with probabilities
- The probability of an accidental explosion due to each base accident is related (*Risk from handling explosives in ports*, HSE, 1995)
- TNO has developed the **TNO transhipment Tool (TTT)** for this purpose:
    - Number of handling actions conducted with containerized munitions
    - Annual frequency of the transhipment activity

Base accident	Unit	Base accident /unit	Explosion /base accident	P_e
Truck on fire	km	$5 \cdot 10^{-9}$	1	$1 \cdot 10^{-6}$
Truck collision	km	$1 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$2 \cdot 10^{-8}$
Train on fire	trains	$4 \cdot 10^{-9}$	1	$8 \cdot 10^{-9}$
Train derailment	trains	$3 \cdot 10^{-7}$	$1 \cdot 10^{-3}$	$6 \cdot 10^{-10}$
Accident with reach stacker	lift	$2.5 \cdot 10^{-6}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-6}$
Sub total				$2.031 \cdot 10^{-6}$

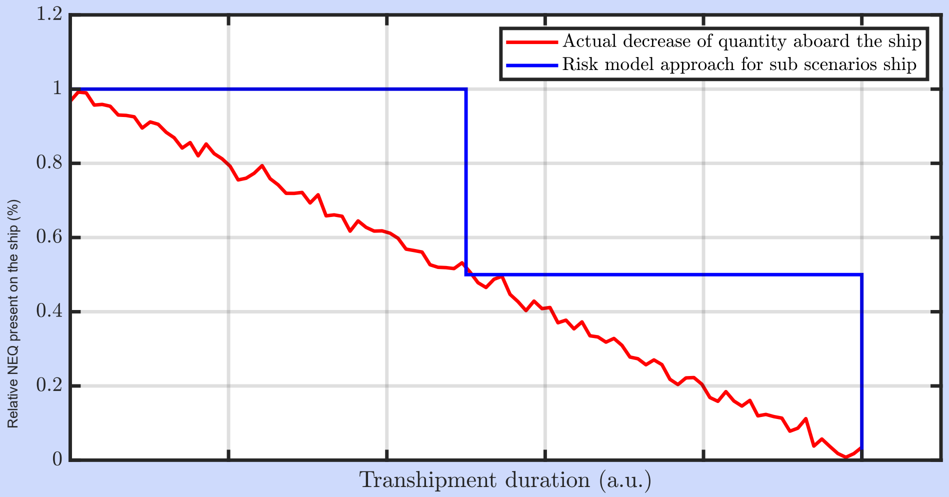
Transhipment scenarios

Sub scenarios

HNS operations involve large amounts; sub scenarios can help achieve acceptable risk in two ways:

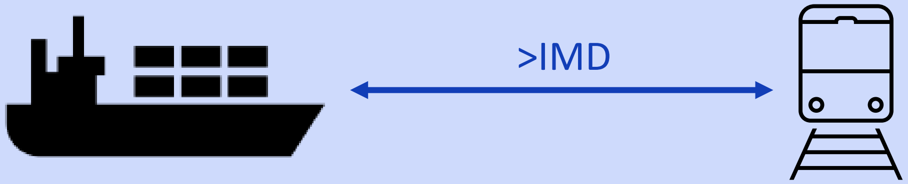
Considering that **the amount gradually decreases** during the transhipment

- Sub scenario a → 100% NEQ for half the duration
- Sub scenario b → 50% of NEQ for other half of the duration

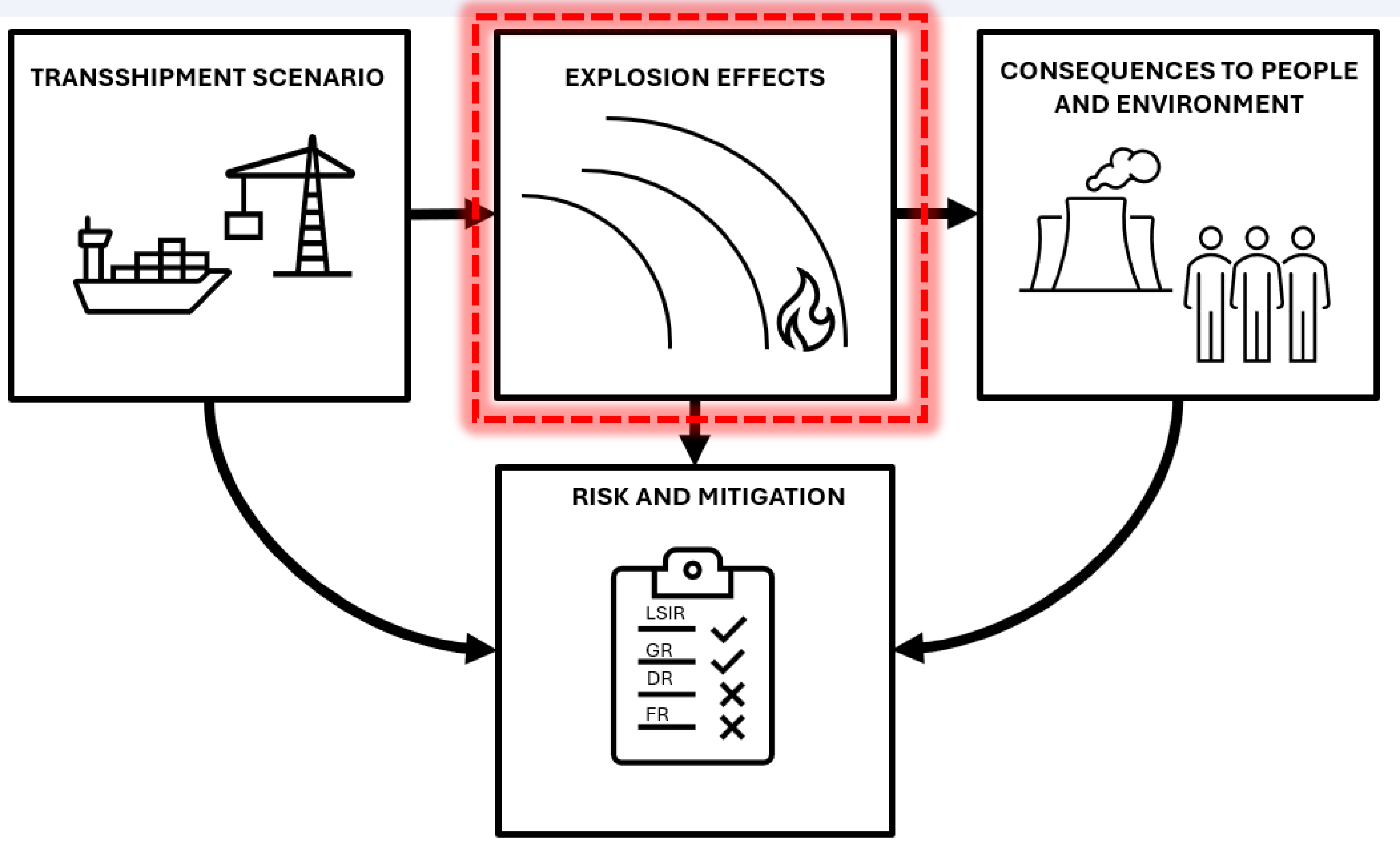


Considering that the ship and train can be considered **two separate PES** when located far enough away (IMD check)

- Sub scenario a → PES ship
- Sub scenario b → PES train



Overview of the risk model



Explosion effects

Blast

- Hemispherical surface burst (Blast Effects Computer)
- Side-on peak pressure (kPa) and impulse (Pa.s), positive phase duration (ms)

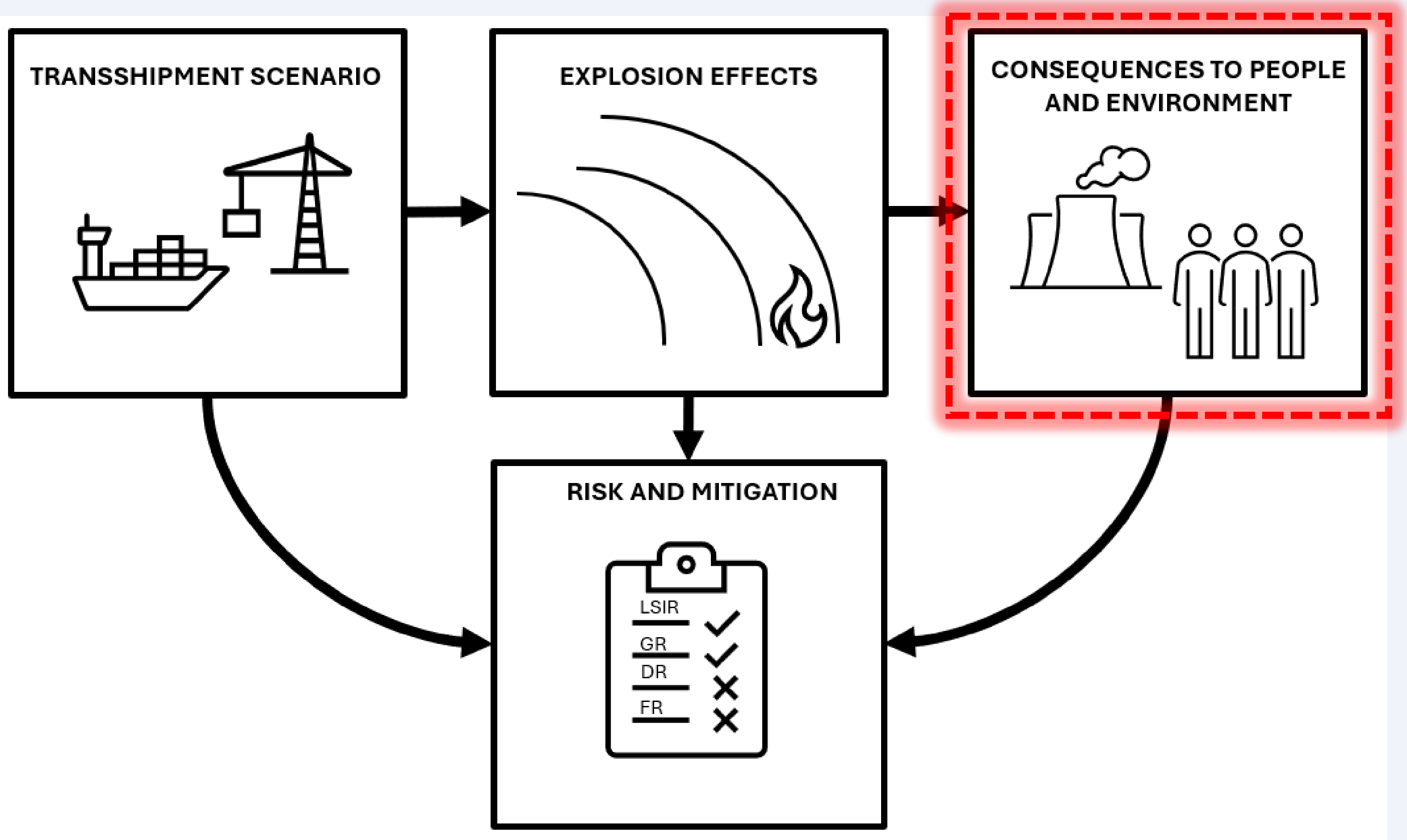
Heat and fire effects

- Fire ball radius (m), irradiance (W/m^2), burn duration (s)
- Models also used in risk-analysis software Risk-NL

Fragment and debris effects (out of scope)

- Lethality in far-field dominated by blast effects
- Vulnerability of industrial installations (e.g. storage tanks) due to debris/fragment hazard is different from blast

Overview of the risk model



Consequence models

Lethality models (probits also used in Risk-NL)

- Head-body injury
- Lung injury
- Thermal injury

→ **Free-field lethality**

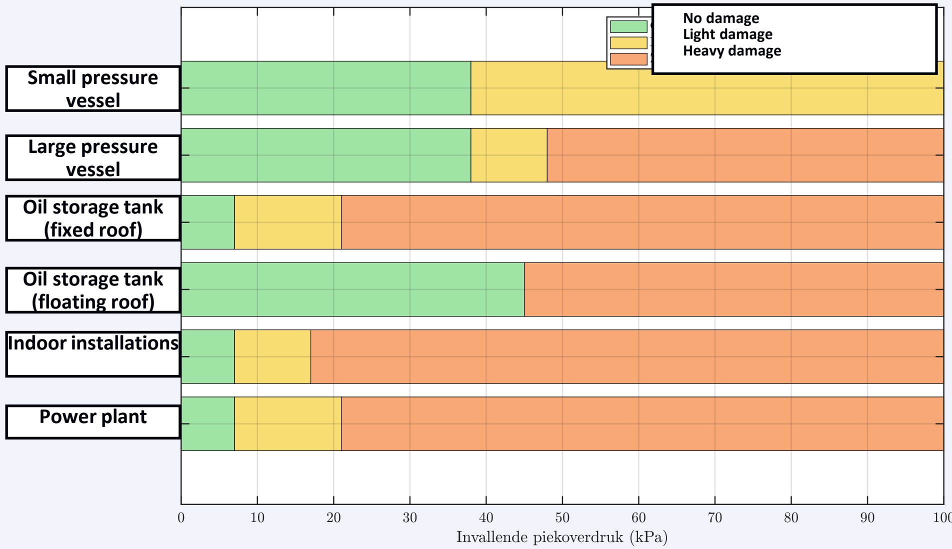
- Inside-building (Gilbert) lethality

Damage to industrial installations

- Peak pressure damage thresholds (kPa) based on numerous studies and reconstructions of historic accidents (e.g. Cyprus)
- Pressure vessels, storage tanks (fixed/floating roof), indoor installations, power plants

Damage to buildings and infrastructure

- Based on construction type (masonry, RC-moment frame, pre-engineered metal buildings)
- Translate damage level to financial loss



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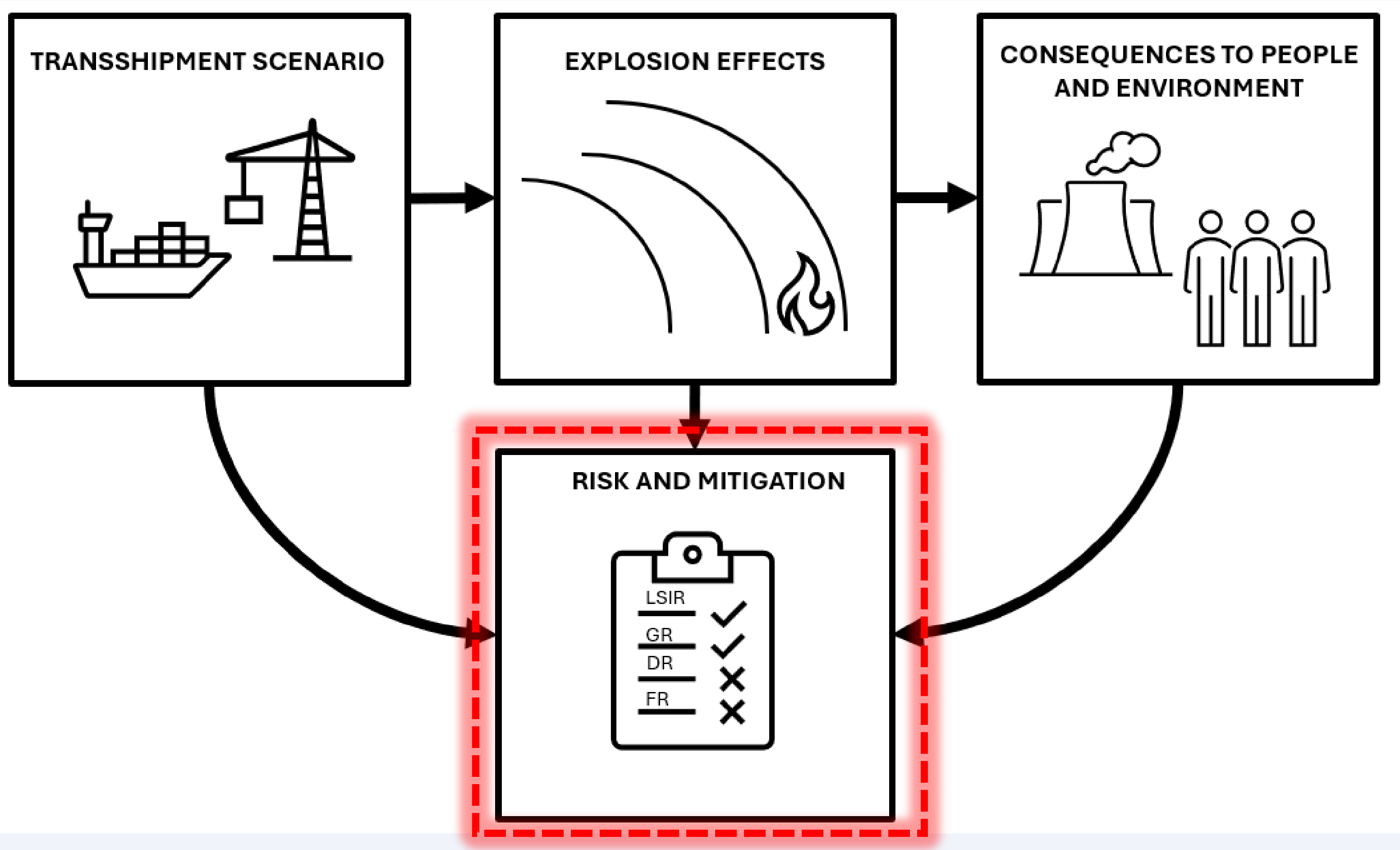


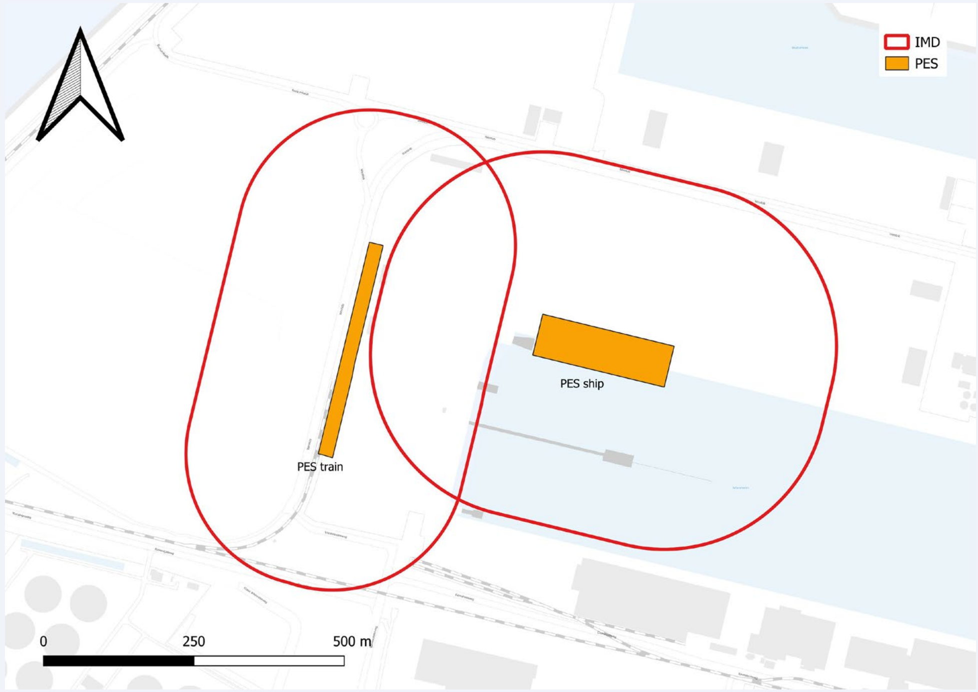
Risk and mitigation (case study)

Transhipment scenarios

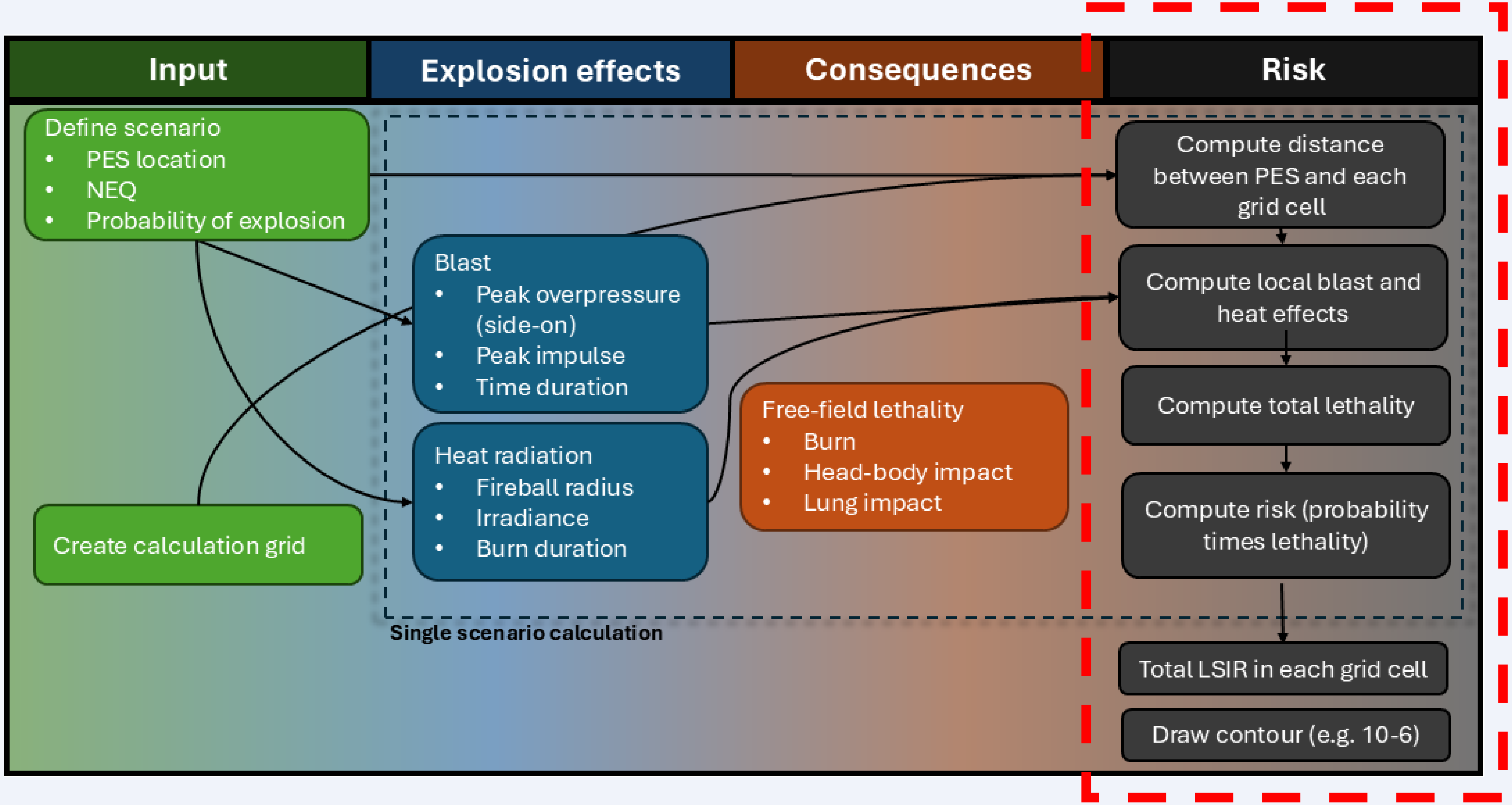
Two transhipment scenarios are defined for this case study:

1. Larger quantity, only occurs few times a year (4/year)
   - Transhipment from ship to train using cranes/reach stackers
   - PES train is located further away than the IMD, so a sub scenario can be introduced for PES train
2. Smaller quantity, can occur on a more frequent basis (40/year)
   - Transhipment from ship directly onto trucks (no train)

Scenario	Location	NEQ (kg TNT eq.)	Freq. (year^{-1})	Annual probability of explosion
1a	PES Ship	200,000	4	$1.5\cdot10^{-5}$
1b	PES Train	100,000	4	$3\cdot10^{-5}$
2	PES Ship	100,000	40	$1\cdot10^{-4}$



Location -specific individual risk

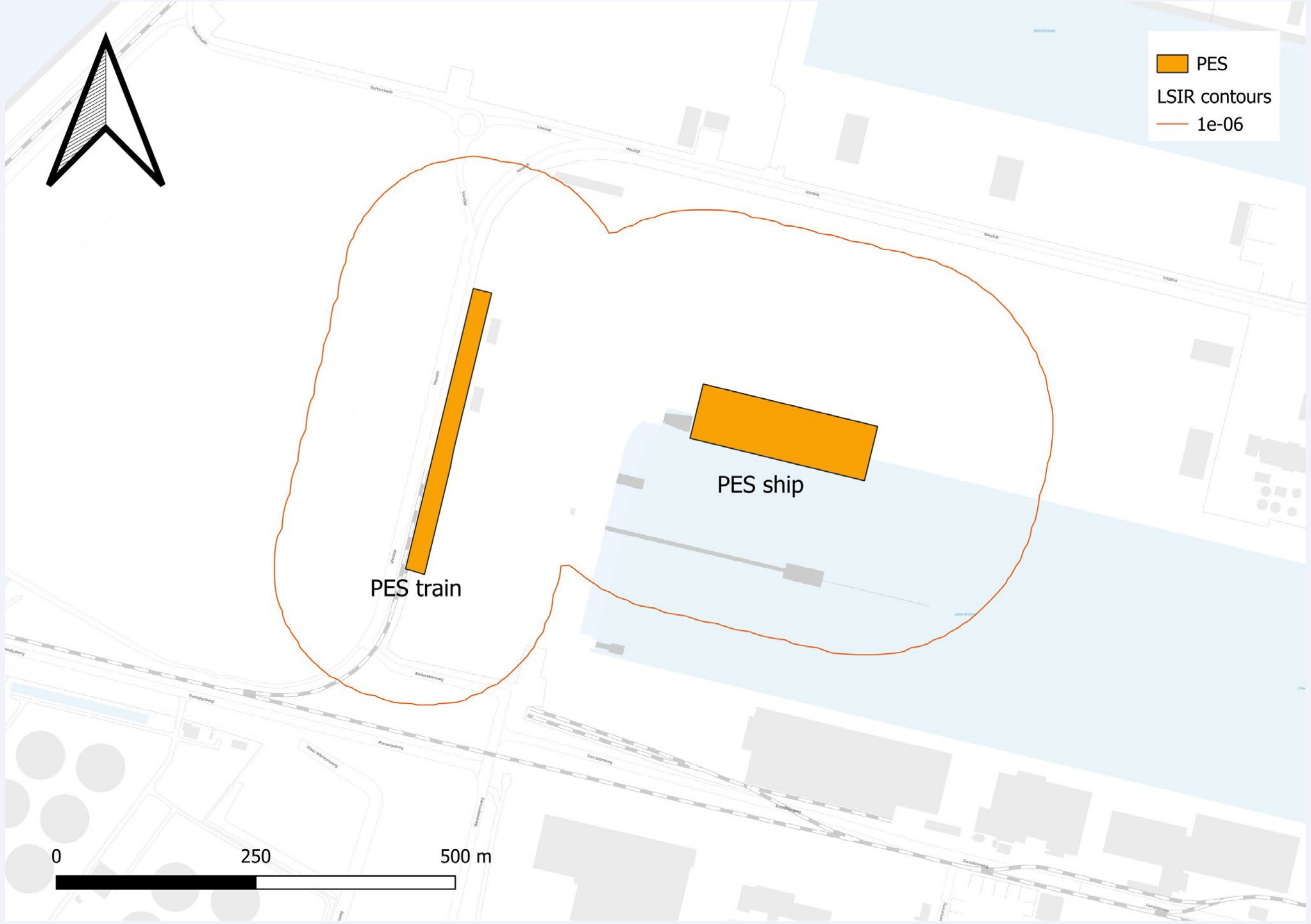


Location-specific individual risk (LSIR) = the probability that an unprotected, continuously exposed person outside of the location dies as a direct result of an accident caused by the activity

Location - specific individual risk

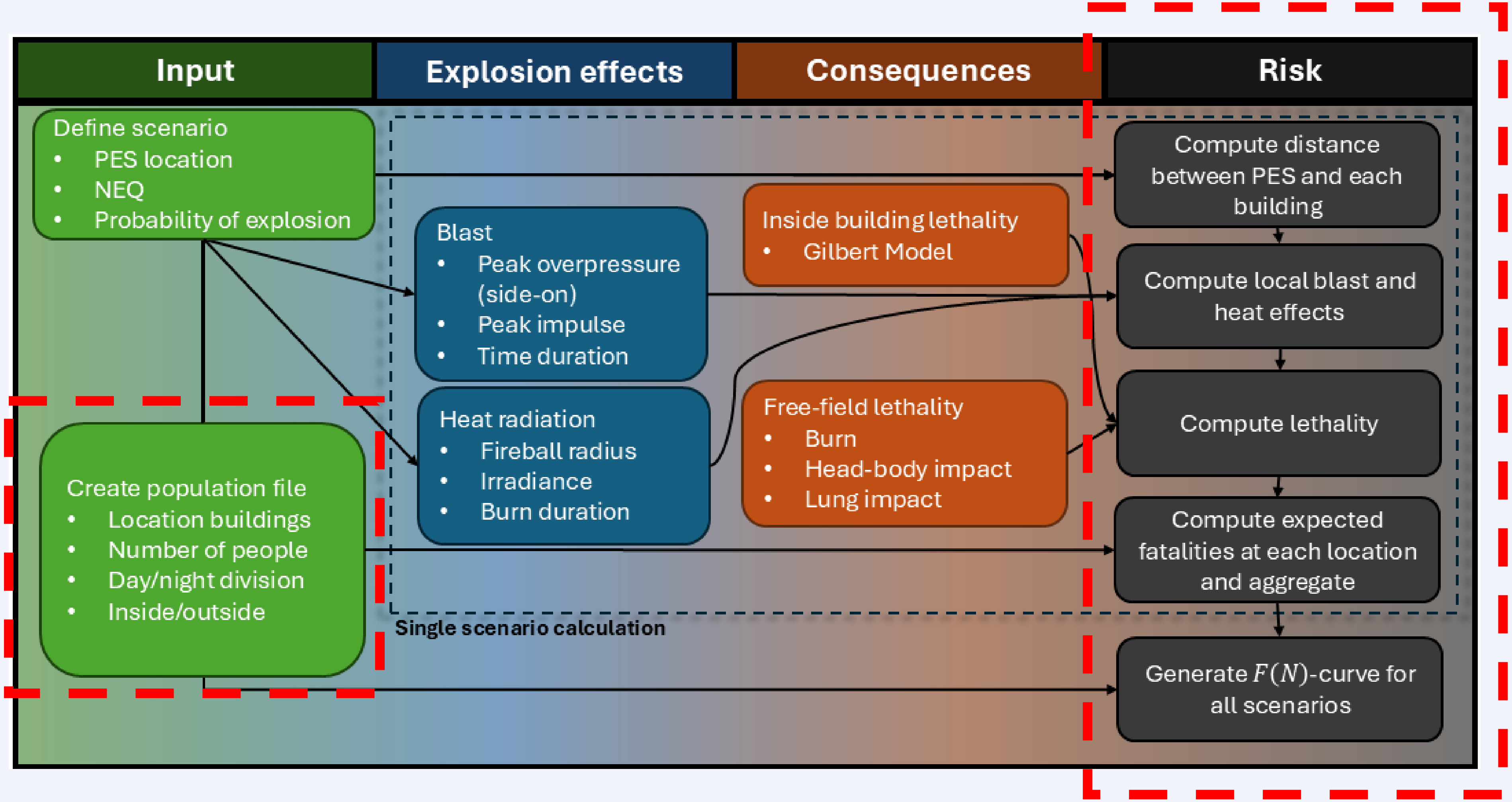
LSIR is calculated for all scenarios combined:

- LSIR = 10^{-6} is common in NL
- Aids stakeholders in communicating and accepting risk
- Helps to determine which activities or types of land-zone use can be allowed for in vicinity



Location-specific individual risk (LSIR) = the probability that an unprotected, continuously exposed person outside of the location dies as a direct result of an accident caused by the activity

Group risk



Group risk = the probability that ten or more persons will die as a direct result of an accidental explosion at the PES (NL definition)

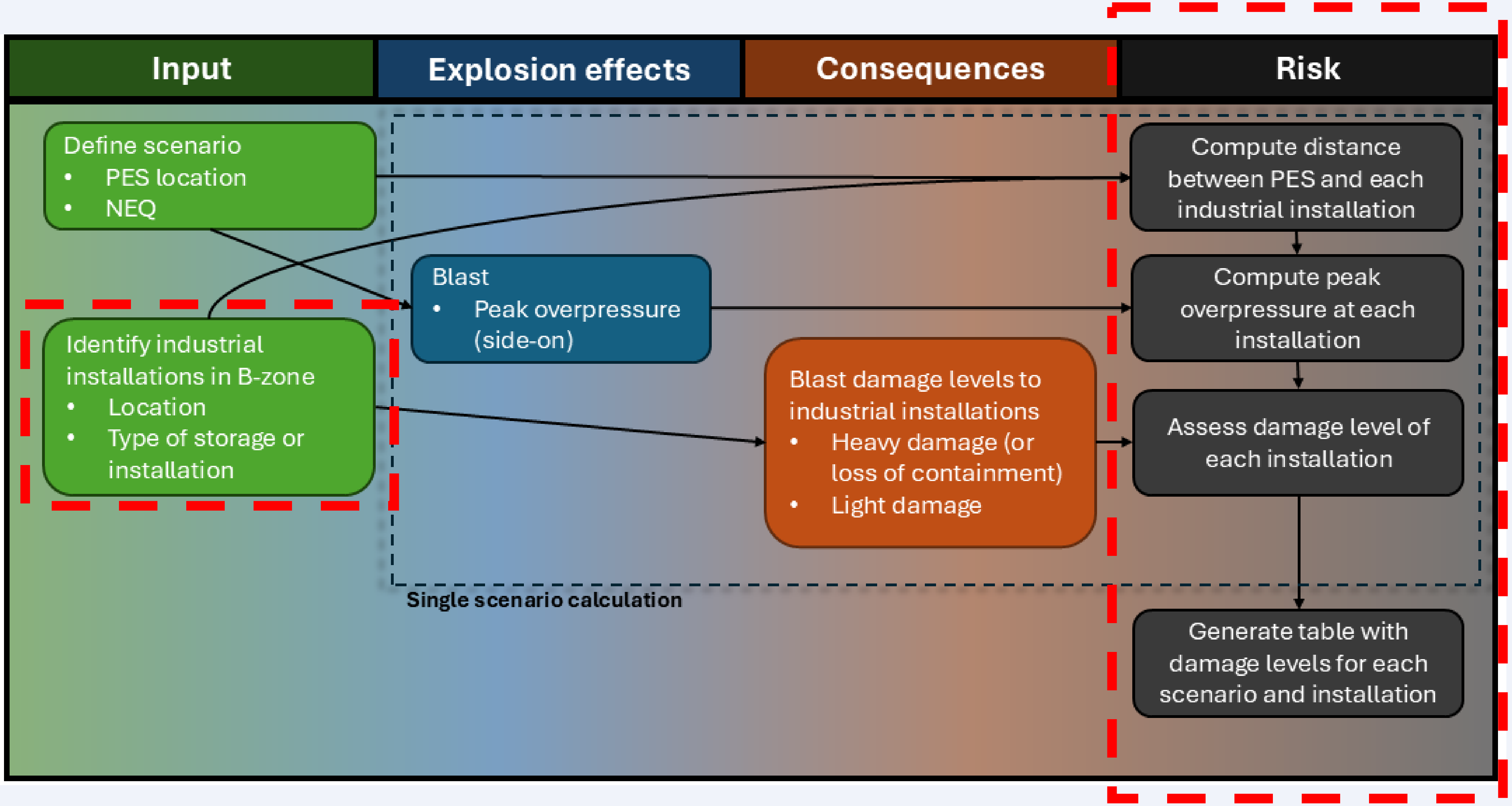
Group risk

- Group risk is expressed in $F(N)$-graphs
- In this case, GR exceeds the orientation values that are commonly maintained in NL:
    - Mitigation of risk by moving transhipment to nighttime is only partially effective

- Additional **risk mitigation strategies** may be necessary:
    - E.g. implementing evacuation or calamity planning procedures

Feature	Value
GR_Combined_01	
Max scenar	Scenario_01b_d
(Derived)	
(Actions)	
01a_d	18,505
01a_n	4,270
01b_d	32,322
01b_n	7,459
02_d	7,484
02_n	1,727
GR_rel [%]	33,3960059700
RMP [%]	37,7311110600
Max sce...	Scenario_01b_d

Domino reactions



Domino reaction = (i) loss of containment of dangerous substances, which pose a direct hazard to human health, or (ii) total loss of power generating production at a power plant

Domino reactions

- Two industrial installations potentially vulnerable to domino reactions identified:
  - Oil storage depot (11 tanks)
  - Power plant
- For all scenarios, the heavy damage threshold (in terms of peak overpressure) is not exceeded
- Iso-pressure contours based on relevant damage threshold are also given, which **mitigate risk** by:
  - Smart siting of new facilities surrounding the transhipment location
  - Setting requirements on the specific type of installations in vicinity

Feature	Value
DR_Scenario_01a	
Damage	Light damage
(Derived)	
(Actions)	
Company	Vopak
Dist PES	767,751
Pso [kPa]	10,384
iso [Pa*s]	NULL
td [s]	NULL
P_thresh	17,00
Damage	Light damage

Facility	Damage threshold (kPa)	Sc. 1a (kPa)	Sc. 1b (kPa)	Sc. 2 (kPa)
Oil storage site	Heavy: 21 Light: 7	10.4	18.2	7.74
Power plant	Heavy: 21 Light: 7	2.52	2.37	2.37

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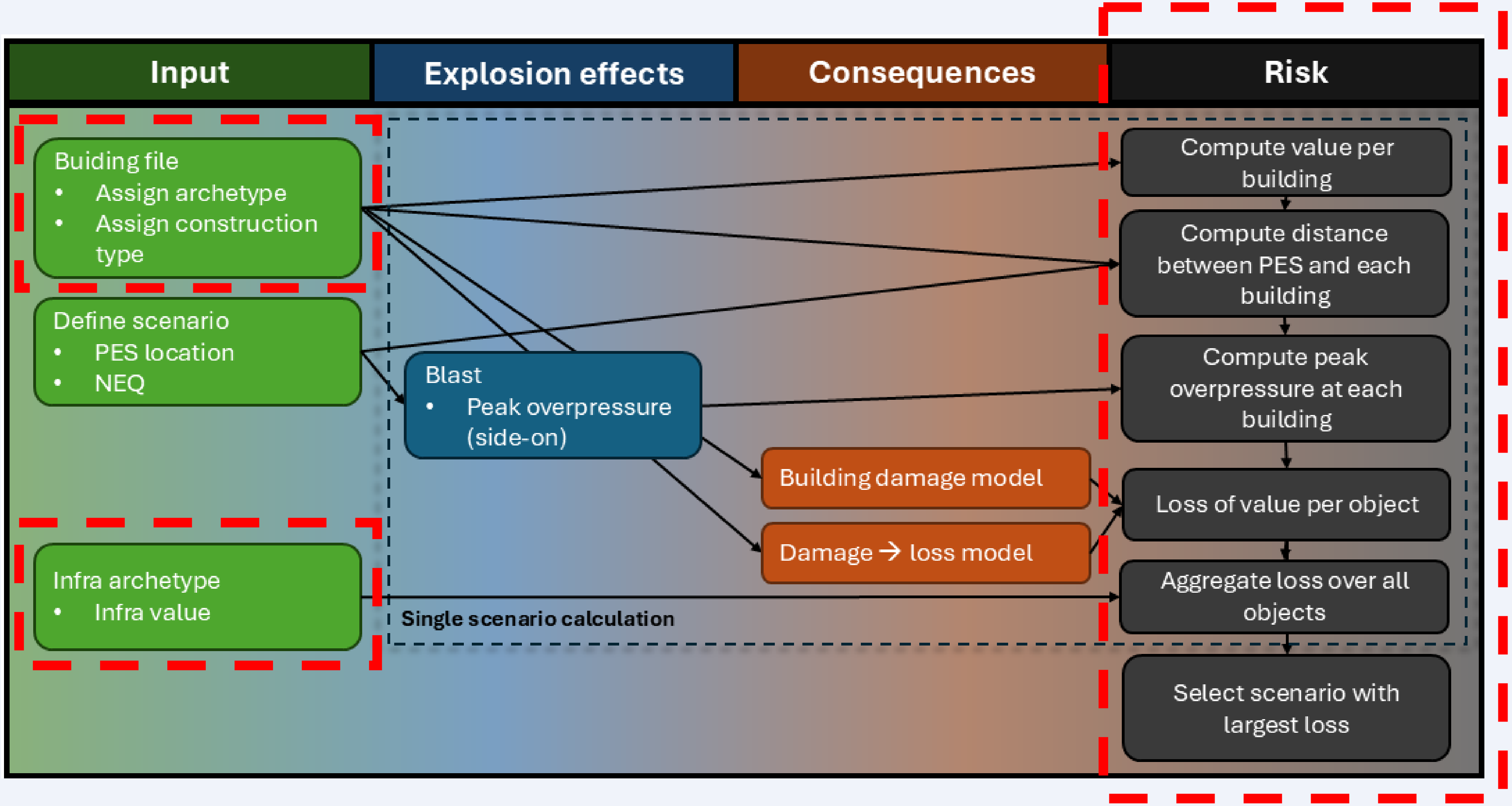
Financial risk

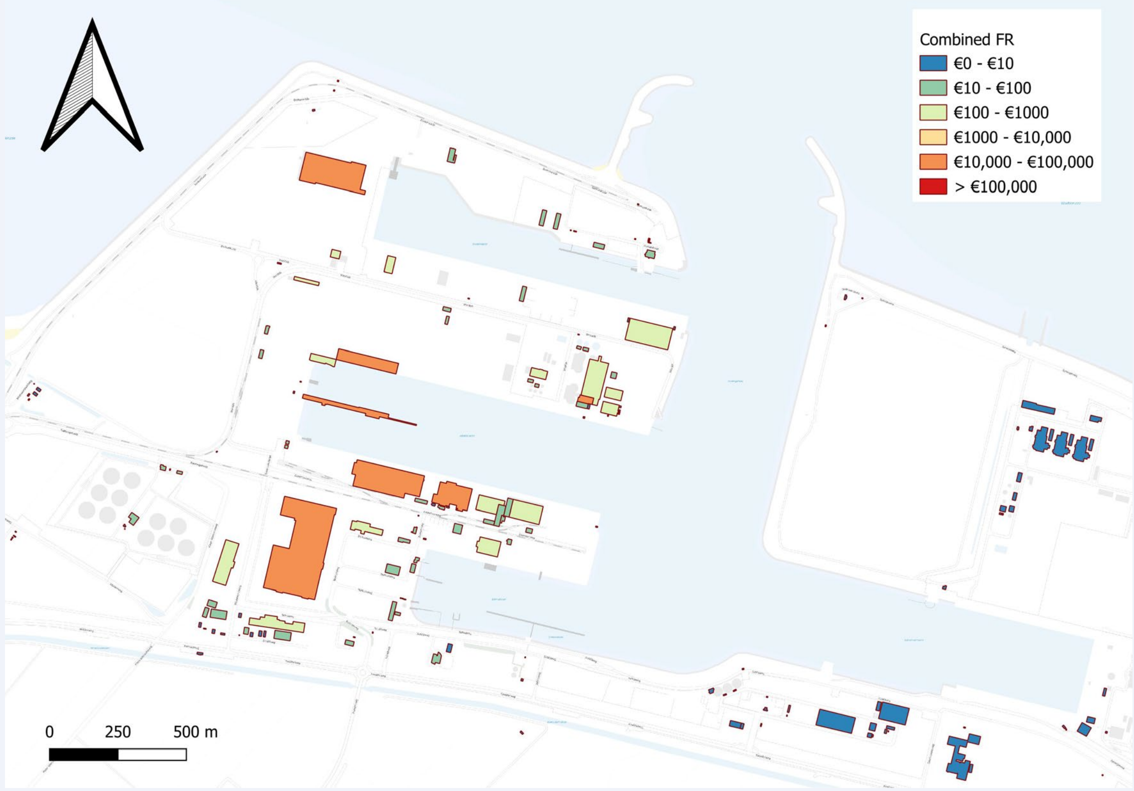


Financial risk provides a lower bound estimation of the financial loss in case of an accidental explosion

Financial risk

- Estimated financial loss based on blast damage to buildings
    - Other types of damage/loss, e.g. down-time of port facilities or damaged ships are not included
- Serves as a lower bound estimation of the financial costs
    - Informative for international operations with different host and sending nation

- The **expected annual loss** can be found through multiplying the expected loss with the accident probability



Scenario	Estimated loss [10^6 EUR]	Relative loss [% of total value]	Expected annual loss [EUR]
1a	155	20.2	2326
1b	112	14.6	3356
2	135	17.7	13,540

Conclusion

- Comprehensive framework for carrying out QRAs for large-scale munition transhipments in seaports
    - Notion of risk is extended to include risk of domino reactions and financial risk, besides third-party risk
    - Transhipment sub scenarios help achieve manageable risk
- Practical application of the methodology in real-life gives clear insights to MoD stakeholders

Future work

- Address debris and fragment effects from munitions aboard ships (currently running research program at TNO)
- Improve sub-models for:
    - Damage to industrial installations (P,I-curves, or numerical work)
    - Injury/lethality to individuals in specific building types