Basic Concept for the Quantitative Assessment of Risks in the Transport of Dangerous Goods

Cefic Seminar on Transport Risk Assessment, Brussels, 4 October 2013

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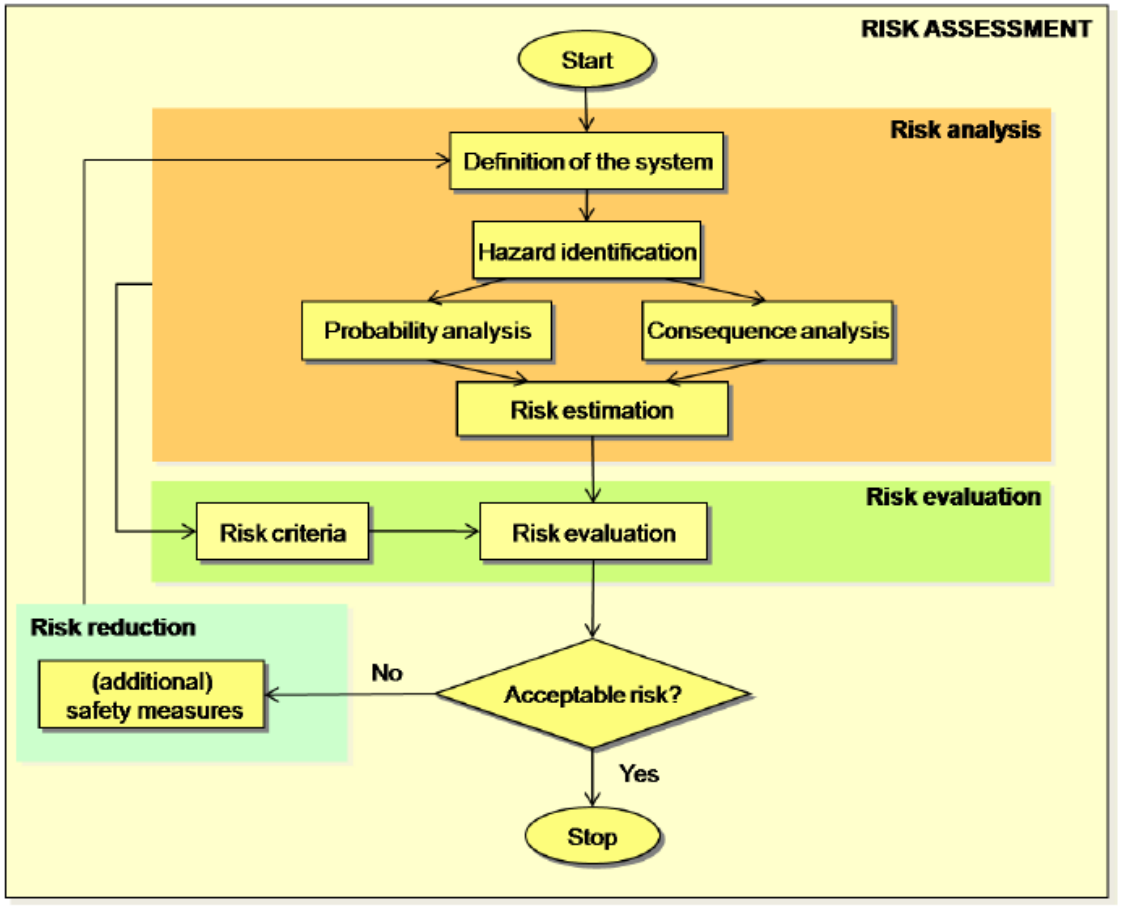
Quantitative Risk Assessment of Transport Operations

General approach



Adopted from: PIARC Technical Committee C.4 Road Tunnel Operation: Technical Report “Risk Evaluation”, Draft Version 5.0_2010

Quantitative Risk Assessment of Transport Operations

General approach

Risk estimation

- Risk $R = I \cdot S$

  Definition of the system + Hazard identification

- Incident frequency rate $I = I(P)$

  Probability analysis

  - Statistical component, function of primal incident probability P

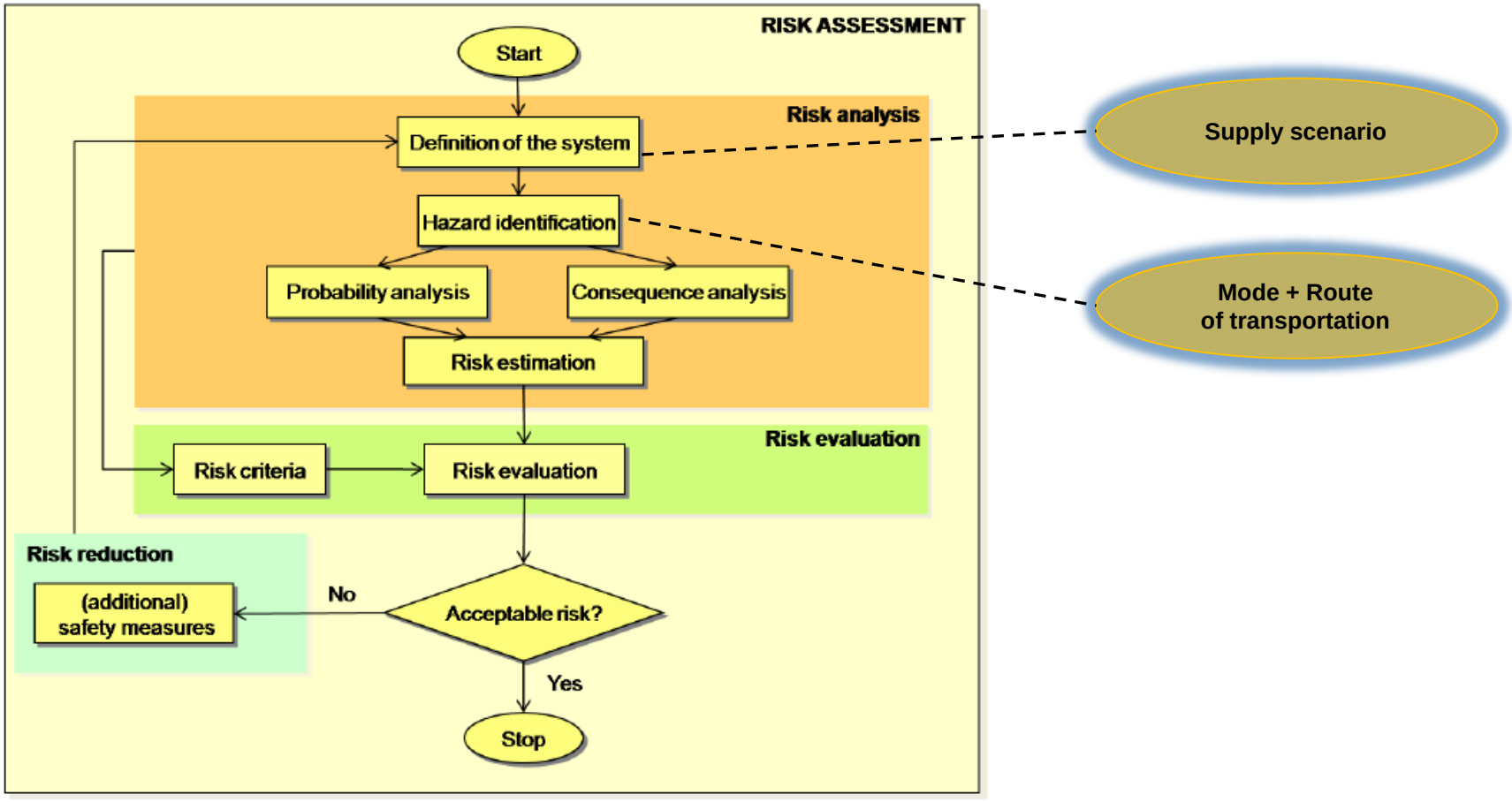
- Severity of harm caused by the incident S

  Consequence analysis

  - Potential extent of consequences, e.g. damage to property, environment and persons

Quantitative Risk Assessment of Transport Operations

BASF approach



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Quantitative Risk Assessment of Transport Operations

Master substances and basic incident scenarios

Definition of the system + Hazard identification

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Master substance	Description	Main representative	Potential damage to property, environment and persons
Petrol	Flammable liquid (DG class 3)	Gasoline and similar kinds of fuel, Benzene, organic solvents	• Impact of heat by fire • Pressure impact and flying debris caused by explosion (e.g. BLEVE) • Effects of smoke • Environmental toxcicity
Propane	Flammable gas (DG class 2, division 2.1)	Propane, Butane, hydrocarbons, Vinyl Chloride	• Impact of heat by fire • Pressure impact and flying debris caused by explosion (e.g. BLEVE) • Effects of smoke
Chlorine	Toxic gas (DG class 2, division 2.3)	Chlorine, Hydrogen Chloride, Ammonia	• Toxicity by inhalation
Trinitrotoluene (TNT)	Explosive solid (DG class 1, division 1.1)	TNT, Ammonium Nitrate, Ammonium Perchlorate	• Pressure impact and flying debris caused by detonation

Adopted from: BIS Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH, Dezember 2006: Risikoanalyse zum Transport gefährlicher Güter im Trogtunnel Cherbourger Straße

Quantitative Risk Assessment of Transport Operations

Severity levels and consequence classes

Definition of the system + Hazard identification

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For each master substance:

- Assignment of incident scenarios to severity levels

Incident Scenario / Master Substance	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4
Flammable liquid (Petrol)	Small leakage	Formation of a pool w/o ignition	Formation of a pool w/ ignition	Rupture of the tank, undergrate fire (BLEVE), huge blaze, flying debris
Flammable gas (Propane)		Leakage w/o ignition	Jet fire	Rupture of the tank, undergrate fire (BLEVE), huge blaze, flying debris
Toxic gas (Chlorine)		Mid-size leakage	Large leakage	Huge leakage, immediate loss of content
Explosive solid (TNT)	Fire impact on packaging	Combustion	Fire / deflagration	Explosion

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Quantitative Risk Assessment of Transport Operations

Severity levels and consequence classes

Definition of the system
+
Hazard identification

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For each master substance:

- Evaluation of the severity levels by consequence classes for different indicators of damage

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300
Injuries	0	1 - 3	4 - 10	11 - 30	31 - 100	101 - 300	301 - 1000	> 1000
Damage to property [Mio. €] (vehicles, cargo, environment)	0 - 0.002	0.002 - 0.01	0.01 - 0.1	0.1 - 0.3	0.3 - 1	1 - 3	3 - 10	> 10
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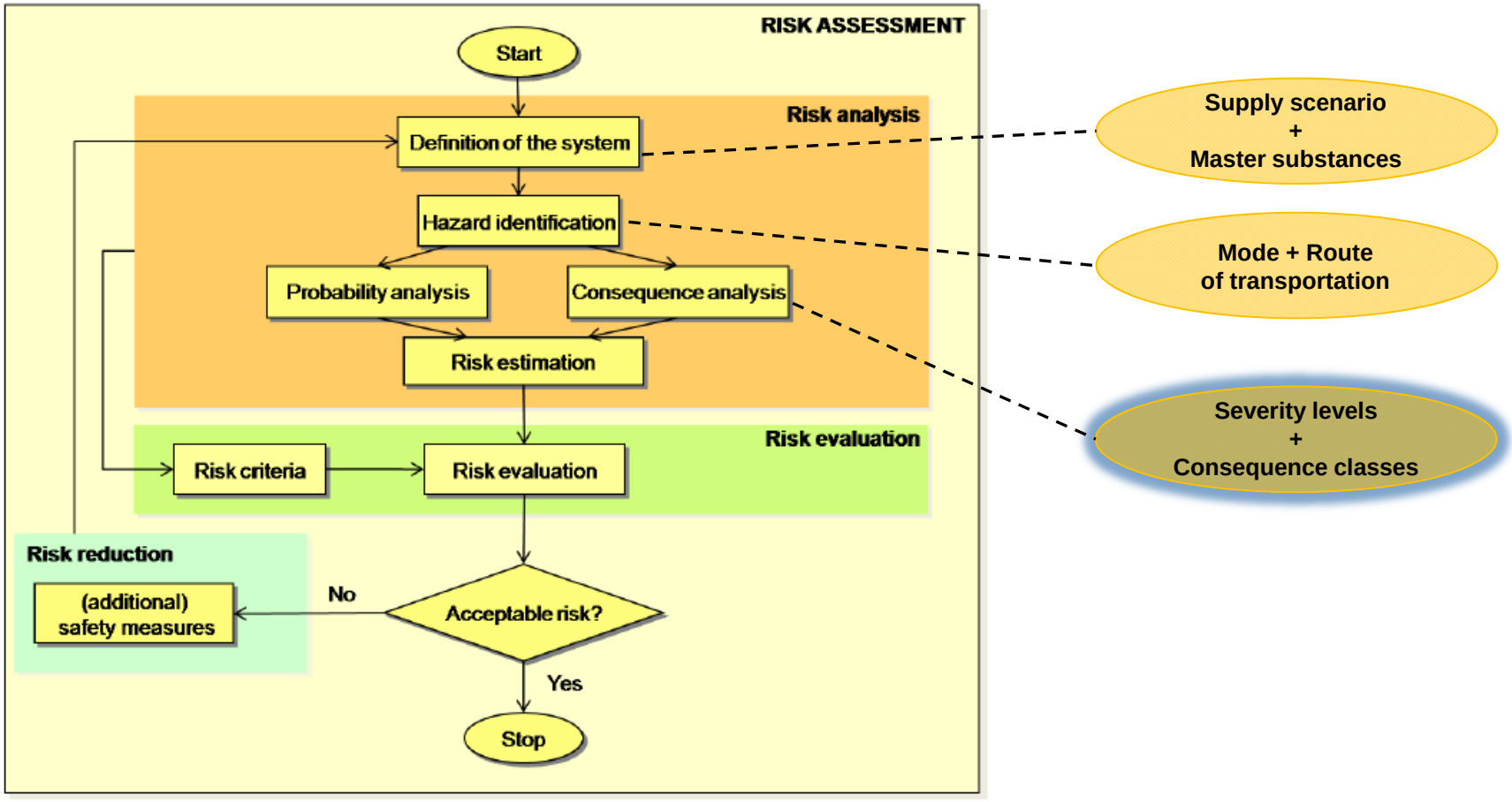
Quantitative Risk Assessment of Transport Operations

BASF approach



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Quantitative Risk Assessment of Transport Operations

Modeling of consequences

Consequence analysis

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For each master substance:

- Assignment of incident scenarios to severity levels

Incident scenario / Master substance	Severity level 1	Severity level 2	Severity level 3	Severity level 4
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- Evaluation of the severity levels by consequence classes for different indicators of damage

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300
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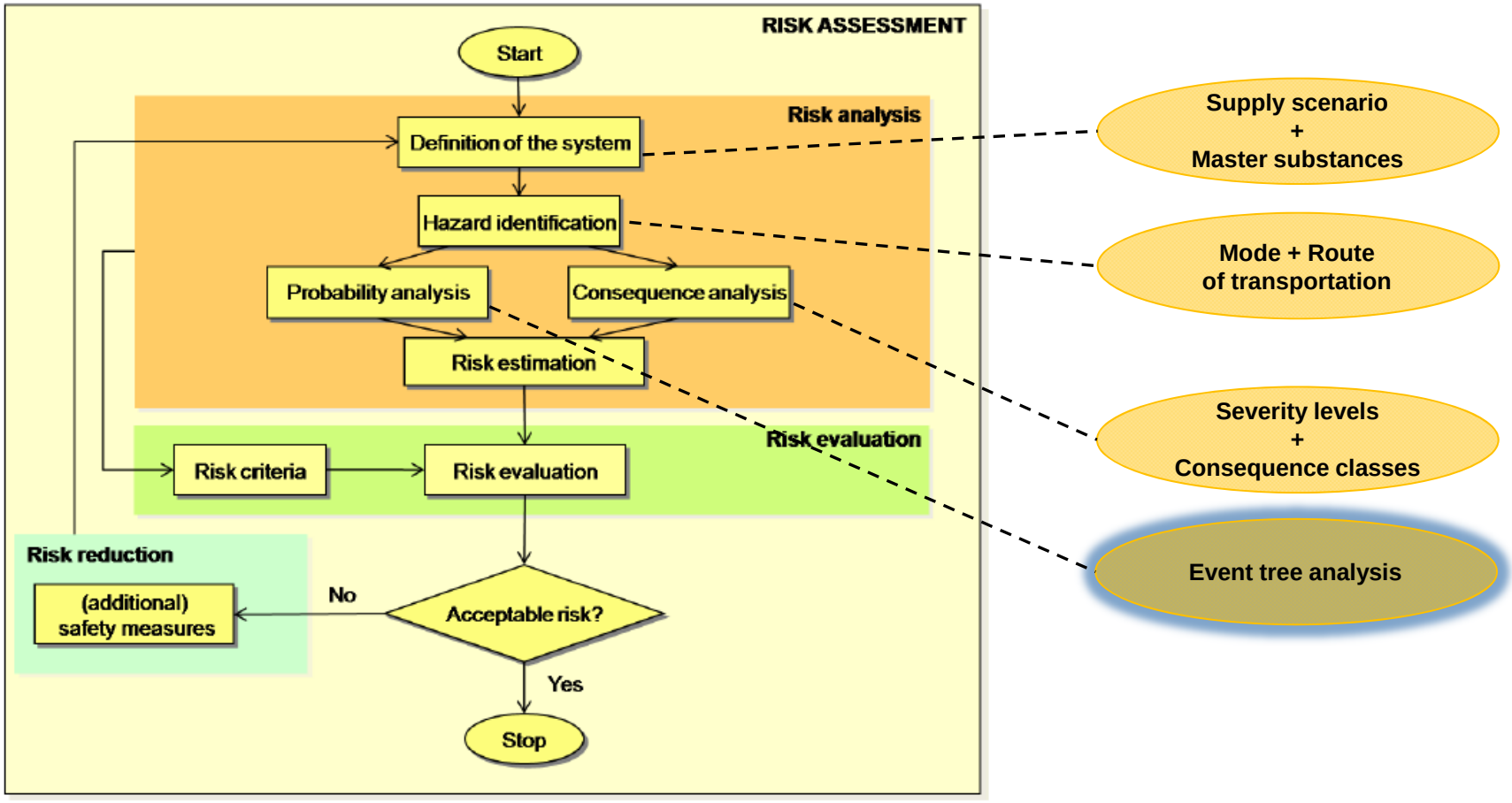
Quantitative Risk Assessment of Transport Operations

BASF approach



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Quantitative Risk Assessment of Transport Operations

Event tree analysis (Risk estimation)

Event tree analysis

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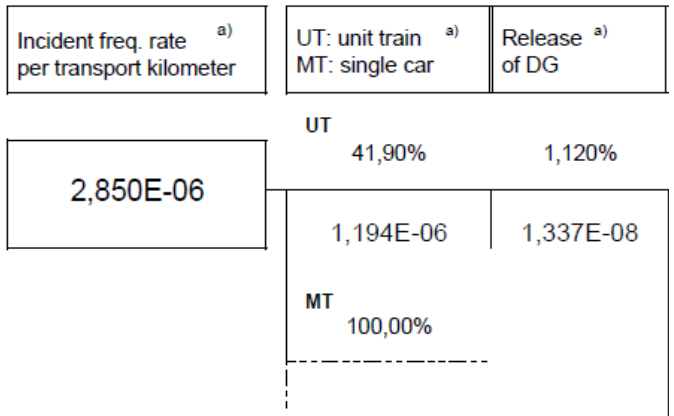
Accidents in Rail Fright Transportation

Statistical KPI (per year)



Mode of Transport

normalized on transport kilometer

- **Basic input to compare different routes for the same mode of transport and the same cargo, where the extent of consequences of an incident is considered to be similar**
- **Further details necessary to compare scenarios with different products to be shipped and different modes of transport**

Ref.: a) U.S. Department of Transportation DOT
b) FOA Memo 00-5231/S: Risk and consequence analysis of ethylen oxide transport by train (October 2000)
c) BIS Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH: Risikoanalyse zum Transport gefährlicher Güter im Trogtunnel Cherbourger Straße (Dezember 2006)

Quantitative Risk Assessment of Transport Operations

Risk estimation

Probability analysis + Consequence analysis

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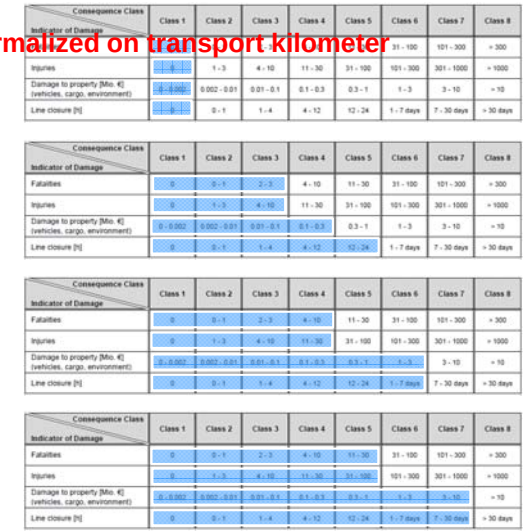
Accidents in Rail Fright Transportation

Statistical KPI (per year)

Incident freq. rate per transport kilometer [a]	UT: unit train MT: single car [a]	Release of DG [a]	Severity level [b] 1 - 4	Scenario specific for master substance: Evaluation of extent of consequences [c] MS: Propane/Chlorine (e.g. EO)
2,850E-06	UT 41,90%	1,120%		
	1,194E-06	1,337E-08	1 90,00%	1,204E-08
	MT 100,00%		2 3,00%	4,012E-10
			3 6,90%	9,228E-10
			4 0,10%	1,337E-11

Master Substance

normalized on transport kilometer



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Quantitative Risk Assessment of Transport Operations

Farmer – diagram to visualize the risk profile

Risk estimation

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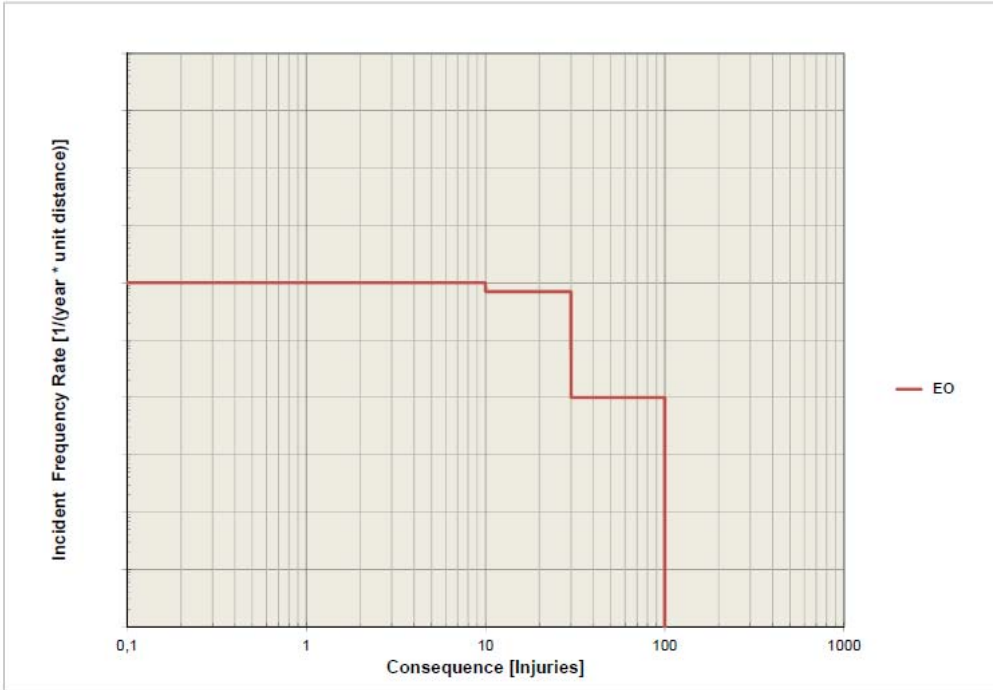
- Display of the risk profile in the Farmer – diagram, i.e. the cumulative incident frequency rate per year vs. the consequence classes

$$I_i(S) = \sum_k I_i \cdot \varphi_{ik}(S_{ik} \geq S)$$

- The risk profile illustrates the distribution of consequences and differentiates between high-frequency, low consequence incidents and low-frequency, high consequence incidents



Quantitative Risk Assessment of Transport Operations

Farmer – diagram to visualize the risk profile

Risk estimation

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- Estimation of the consequences specific for the master substance:

  Petrol, UN1203 (3,II), F1

Severity level 1

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300
Injuries	0 - 1	1 - 3	4 - 10	11 - 30	31 - 100	101 - 300	301 - 1000	> 1000
Damage to property [Mio. €] (vehicles, cargo, environment)	0 - 0.002	0.002 - 0.01	0.01 - 0.1	0.1 - 0.3	0.3 - 1	1 - 3	3 - 10	> 10
Line closure [h]	0	0 - 1	1 - 4	4 - 12	12 - 24	1 - 7 days	7 - 30 days	> 30 days

Severity level 2

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300
Injuries	0 - 1	1 - 3	4 - 10	11 - 30	31 - 100	101 - 300	301 - 1000	> 1000
Damage to property [Mio. €] (vehicles, cargo, environment)	0 - 0.002	0.002 - 0.01	0.01 - 0.1	0.1 - 0.3	0.3 - 1	1 - 3	3 - 10	> 10
Line closure [h]	0	0 - 1	1 - 4	4 - 12	12 - 24	1 - 7 days	7 - 30 days	> 30 days

Severity level 3

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300
Injuries	0	1 - 3	4 - 10	11 - 30	31 - 100	101 - 300	301 - 1000	> 1000
Damage to property [Mio. €] (vehicles, cargo, environment)	0 - 0.002	0.002 - 0.01	0.01 - 0.1	0.1 - 0.3	0.3 - 1	1 - 3	3 - 10	> 10
Line closure [h]	0	0 - 1	1 - 4	4 - 12	12 - 24	1 - 7 days	7 - 30 days	> 30 days

Severity level 4

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300
Injuries	0	1 - 3	4 - 10	11 - 30	31 - 100	101 - 300	301 - 1000	> 1000
Damage to property [Mio. €] (vehicles, cargo, environment)	0 - 0.002	0.002 - 0.01	0.01 - 0.1	0.1 - 0.3	0.3 - 1	1 - 3	3 - 10	> 10
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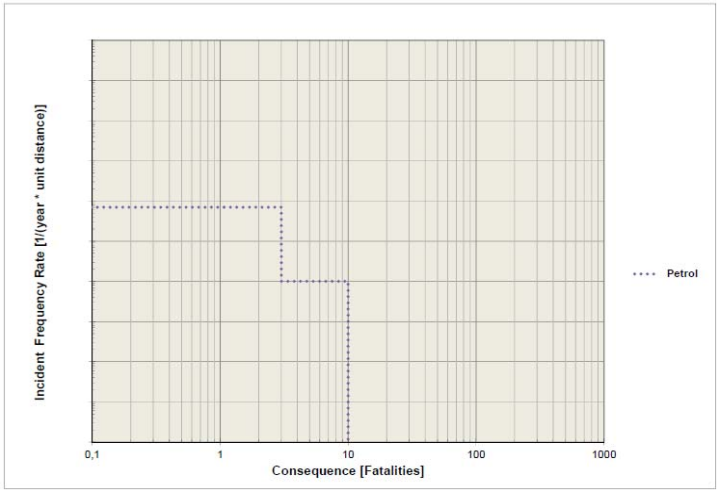

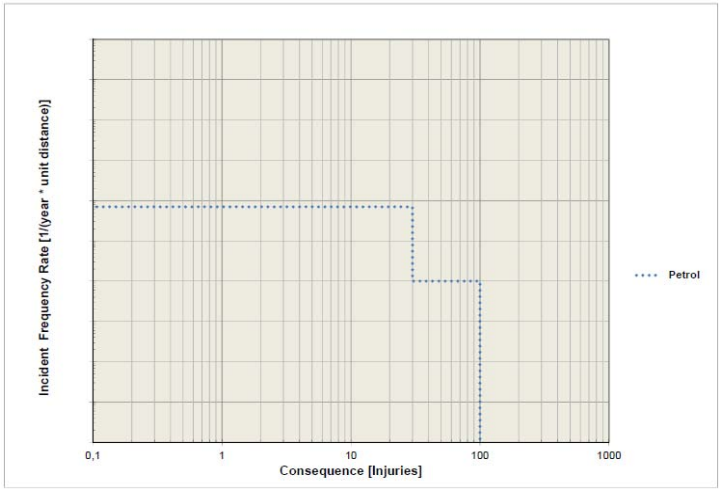

Quantitative Risk Assessment of Transport Operations

Farmer – diagram to visualize the risk profile

Risk estimation

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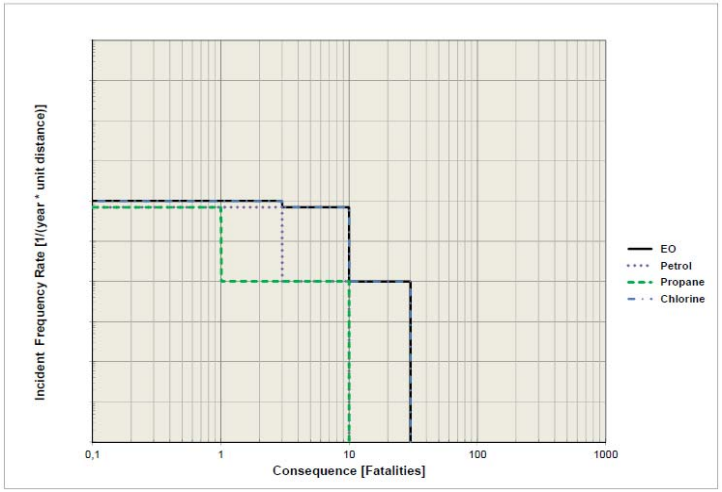
- Estimation of the consequences specific for the master substance:

  Petrol, UN1203 (3,II), F1

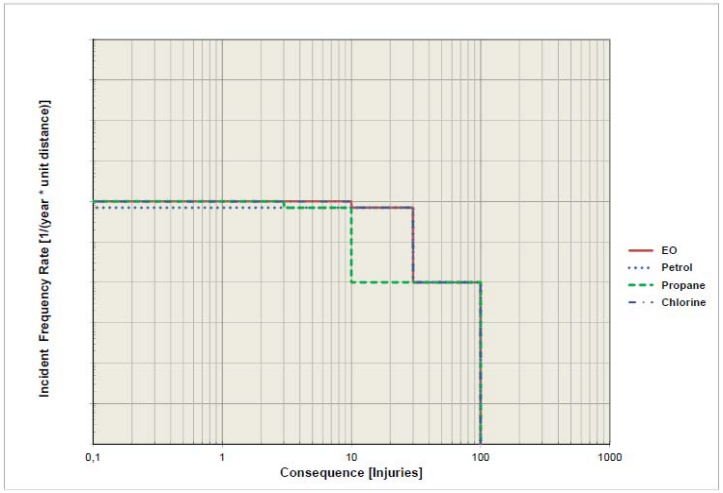
  Propane, UN1978 (2.1), 2F

  Chlorine, UN1017 (2.3 + 8 + 5.1), 2TC



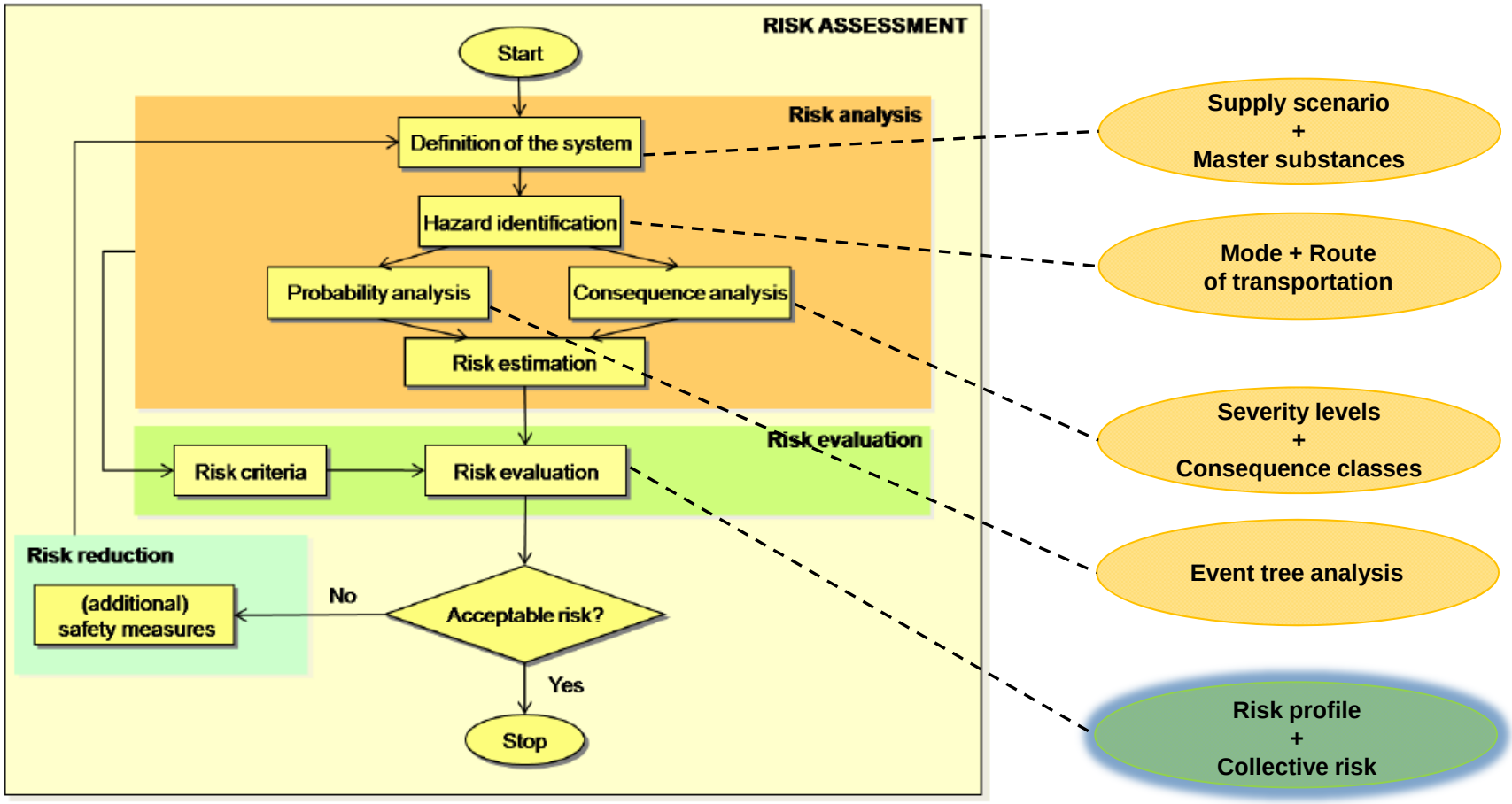
- Estimation of the consequences specific for the benchmark substance:

  EO, UN1040 (2.3 + 2.1), 2TF



Quantitative Risk Assessment of Transport Operations

BASF approach



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Quantitative Risk Assessment of Transport Operations

Risk estimation

Risk evaluation

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Accidents in Rail Fright Transportation

Statistical KPI (per year)

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				4,012E-10
			3	6,90%
				9,228E-10
			4	0,10%
				1,337E-11

Scenario specific for master substance

Evaluation of extent of consequences [c]
MS: Propane/Chlorine (e.g. EO)

Supply scenario

BSW:
600 km; 365 shipments (1100 t each)

Supply Scenario

specific on route and frequency of shipments

Consequence Class / Indicator of Damage	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	
Fatalities	0	0 - 1	2 - 3	4 - 10	11 - 30	31 - 100	101 - 300	> 300	
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Damage to property [Mio. €] (vehicles, cargo, environment)	0 - 0,002	0,002 - 0,01	0,01 - 0,1	0,1 - 0,3	0,3 - 1	1 - 3	3 - 10	> 10	2,000E-03
Line closure [h]	0	0 - 1	1 - 4	4 - 12	12 - 24	1 - 7 days	7 - 30 days	> 30 days	

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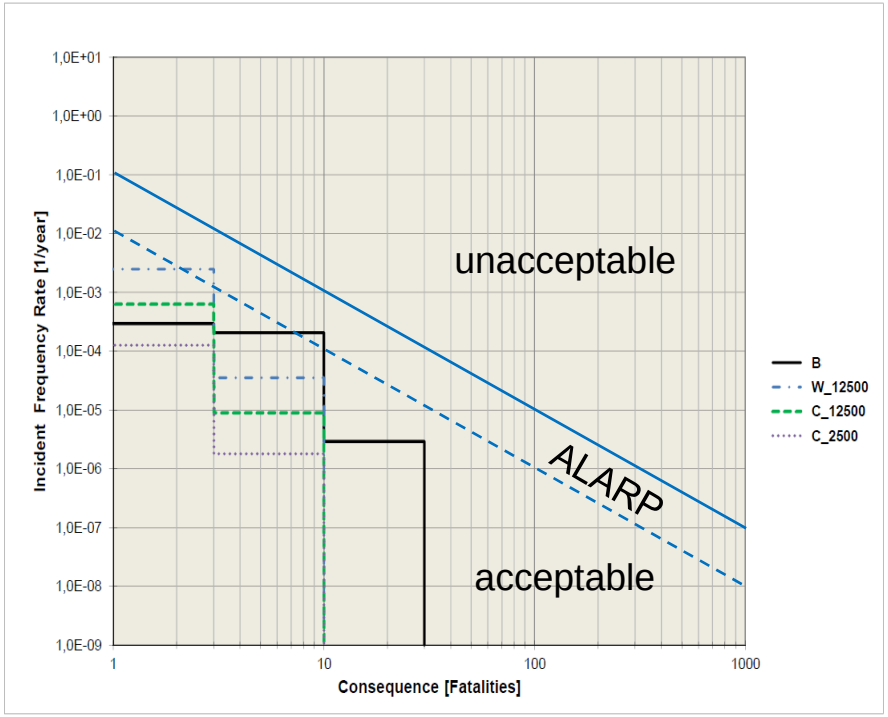
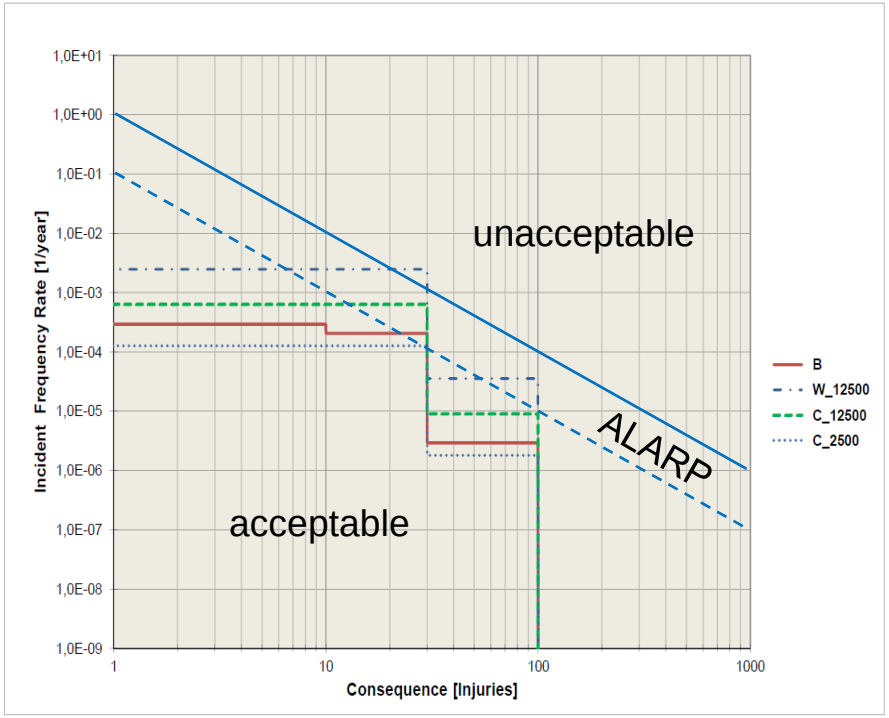
Quantitative Risk Assessment of Transport Operations

Risk evaluation

Risk evaluation

- Comparison of the risk profiles of different supply scenarios of Benzene (Master substance: Petrol) via road transportation with the transportation of EO by rail as a benchmark (B)
- Threshold lines indicating the level of transportation risks excepted by company, business partners or society (tentative!), based on the ALARP principle adopted from risk evaluations for road tunnels
  (PIARC Technical Committee C.4 Road Tunnel Operation: Technical Report “Risk Evaluation”, Draft Version 5.0_2010)





Quantitative Risk Assessment of Transport Operations

Farmer – diagram vs. Collective risk

Risk evaluation

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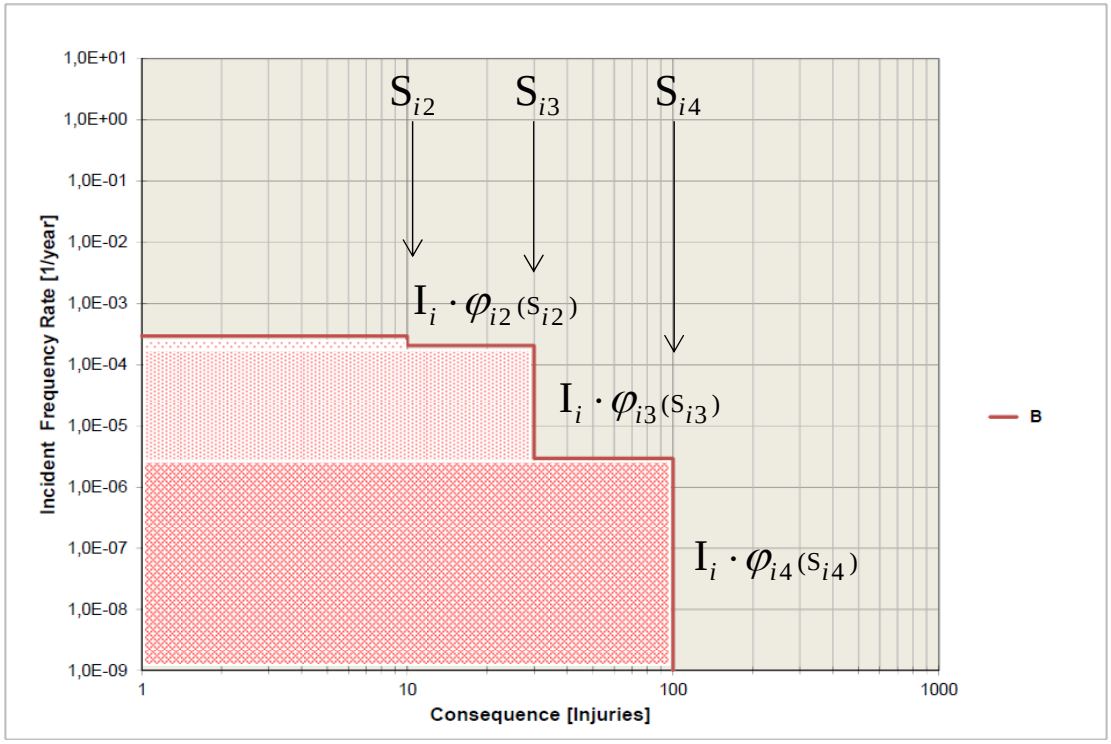
- Display of the risk profile
  (cumulative incident frequency rate)

$$I_i(S) = \sum_k I_i \cdot \varphi_{ik}(S_{ik} \geq S)$$

- Calculation of the collective Risk
  (long-term average number of statistically expected consequences)

$$R_i = \sum_k I_i \cdot \varphi_{ik}(S_{ik}) \cdot S_{ik}$$



Quantitative Risk Assessment of Transport Operations

Collective risk

Risk evaluation

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- Evaluation and comparison of the collective risk specific for each supply scenario

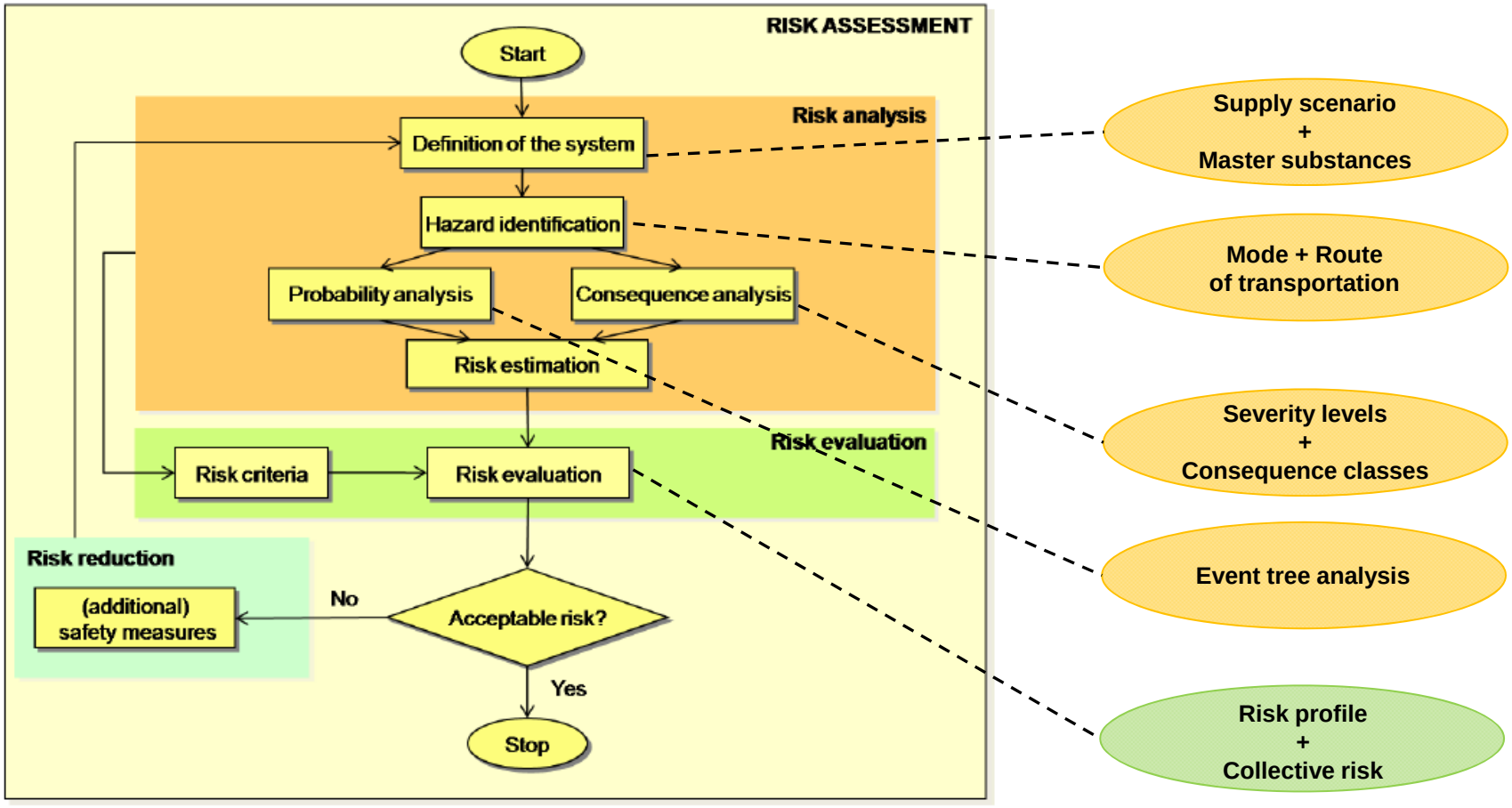
Collective Risk [1/year]

	B	C_2500	C_12500	W_12500
Fatalities	2,372E-03	3,914E-04	1,957E-03	7,676E-03
Injuries	7,235E-03	3,914E-03	1,957E-02	7,676E-02
Damage to property [Mio. €] (vehicles, cargo, environment)	2,159E-03	1,329E-03	6,646E-03	2,607E-02
Line closure [h]	1,603E-01	9,760E-02	4,880E-01	1,915E+00

However, expressing risk in terms of a single number may conceal and obscure important aspects of the specific risk profile, i.e. incidents with very low probability / very high consequences only contribute to a minor extent to the expected value.

Quantitative Risk Assessment of Transport Operations

BASF approach



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