PIARC TUNNEL CONGRESS

RISK – BASED DECISION MAKING IN TUNNEL SAFETY

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WARSAW 07.02.2023

20 YEARS OF TUNNEL SAFETY

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source ÖBB

OUTLINE

- HISTORICAL REVIEW
- RISK-BASED DECISION MAKING – PRINCIPLES
- RISK BASED DECISION MAKING – TOOLS
- PIARC ACTIVITIES IN TUNNEL SAFETY
- CONCLUSIONS & OUTLOOK

HISTORICAL REVIEW

CENTRAL EUROPE, 20 YEARS AGO …

2 catastrophic fires happened in Tauern & Montblanc tunnel within 2 months

- Tunnel safety suddenly came in the focus of public attention, which initiated a dynamic development …

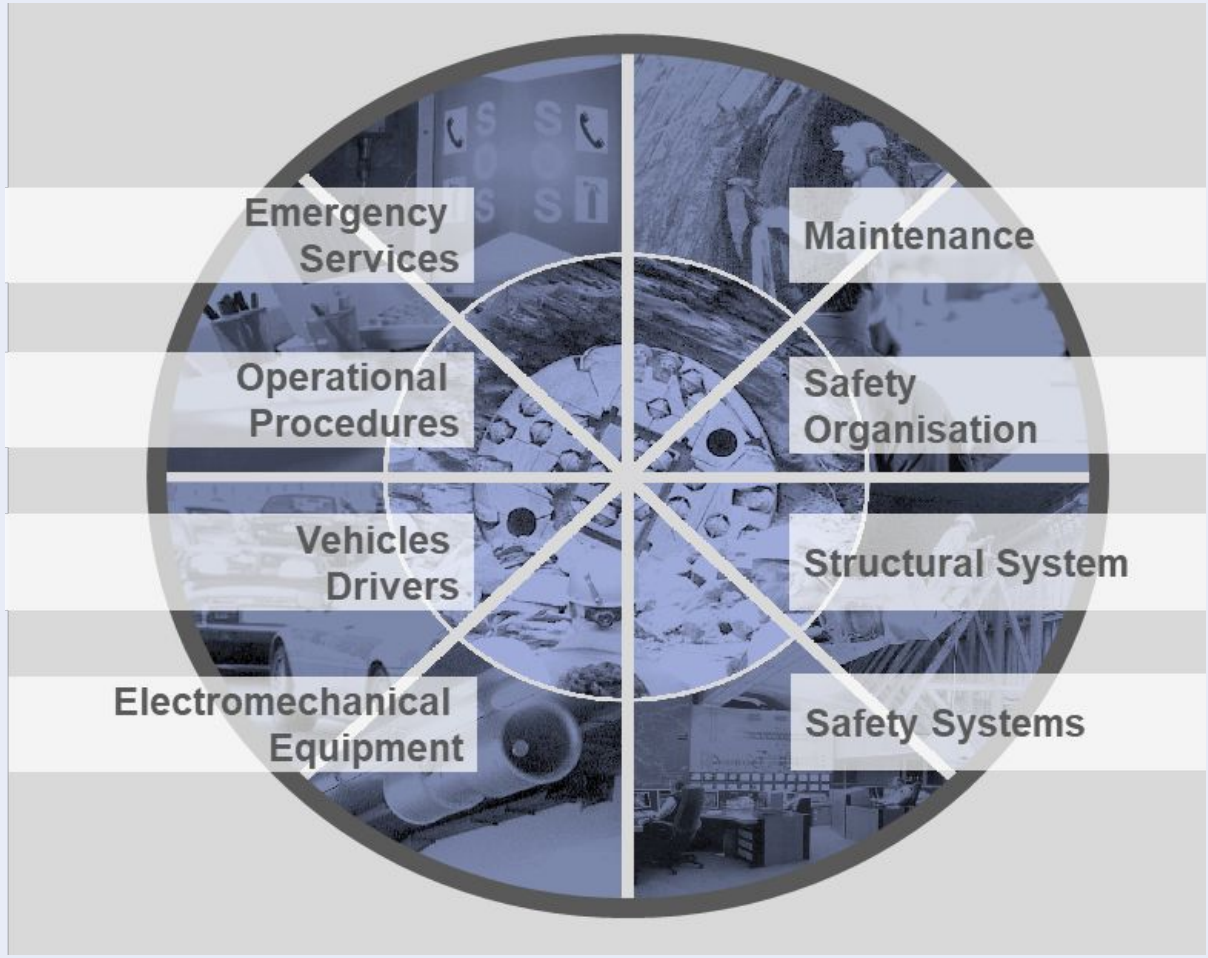
EC-Directive 2004/54/EC on Road Tunnel Safety **as trigger for innovation, harmonization and integration**

- **Definition of generally applicable** minimum safety requirements
- **Implementation of a** modern safety culture – integrated, holistic approach
- **Implementation of new** tools for **road tunnel** safety management **like**
  - Risk assessment
  - Safety inspection
  - Safety documentation
  - Process for feedback from experience


source tunneltalk.com

source: Archiv RK Lungau

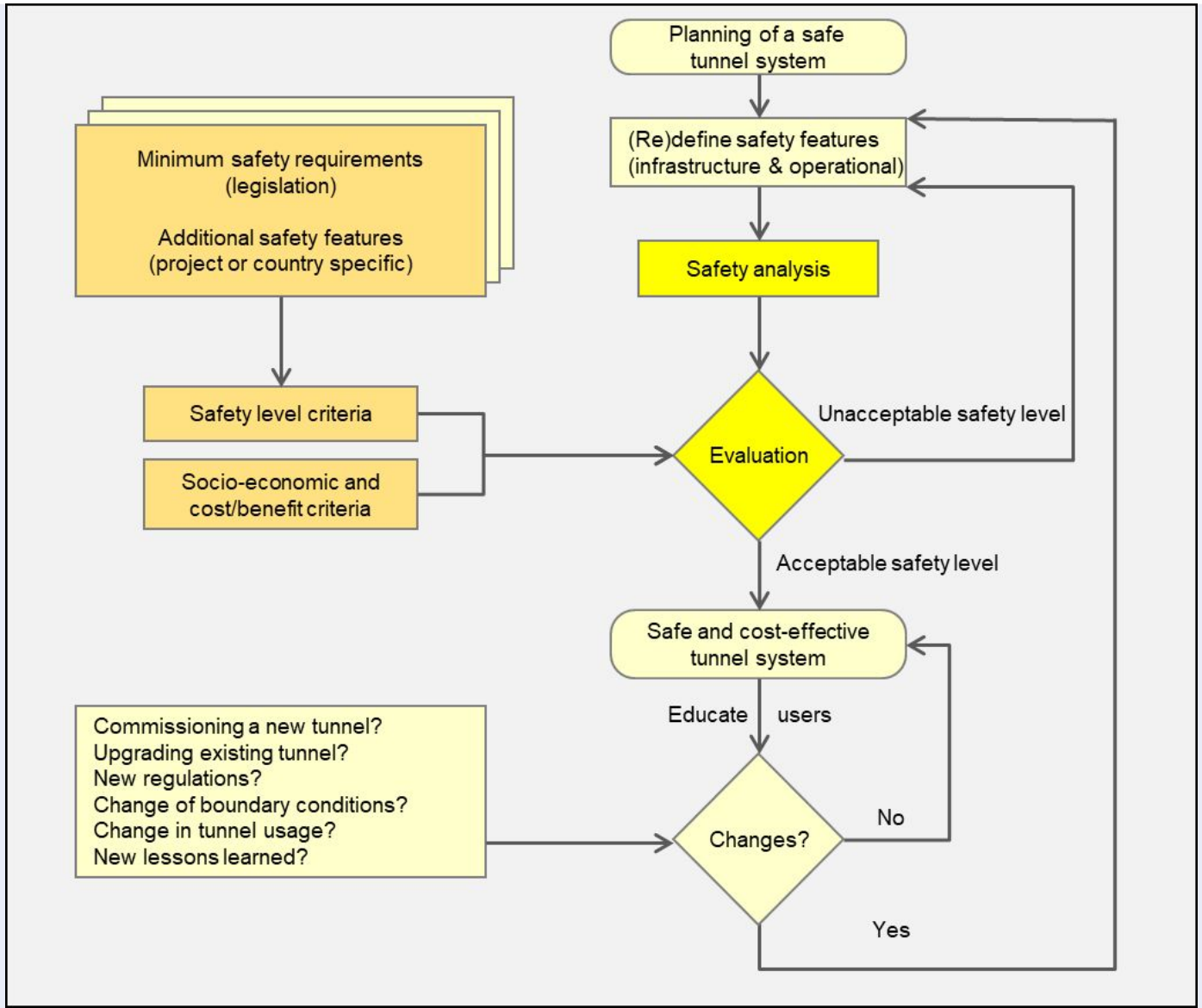
HISTORICAL REVIEW



HOLISTIC VIEW ON TUNNEL SAFETY

- Tunnel incidents are characterized by complex interaction effects
- Taken into account in an integrated holistic approach to tunnel safety (EC-Directive 2004/54/EG)
- Covers all types of significant tunnel incidents (fires, collisions etc.) and all aspects and elements of tunnel system

HISTORICAL REVIEW



INTEGRATED APPROACH

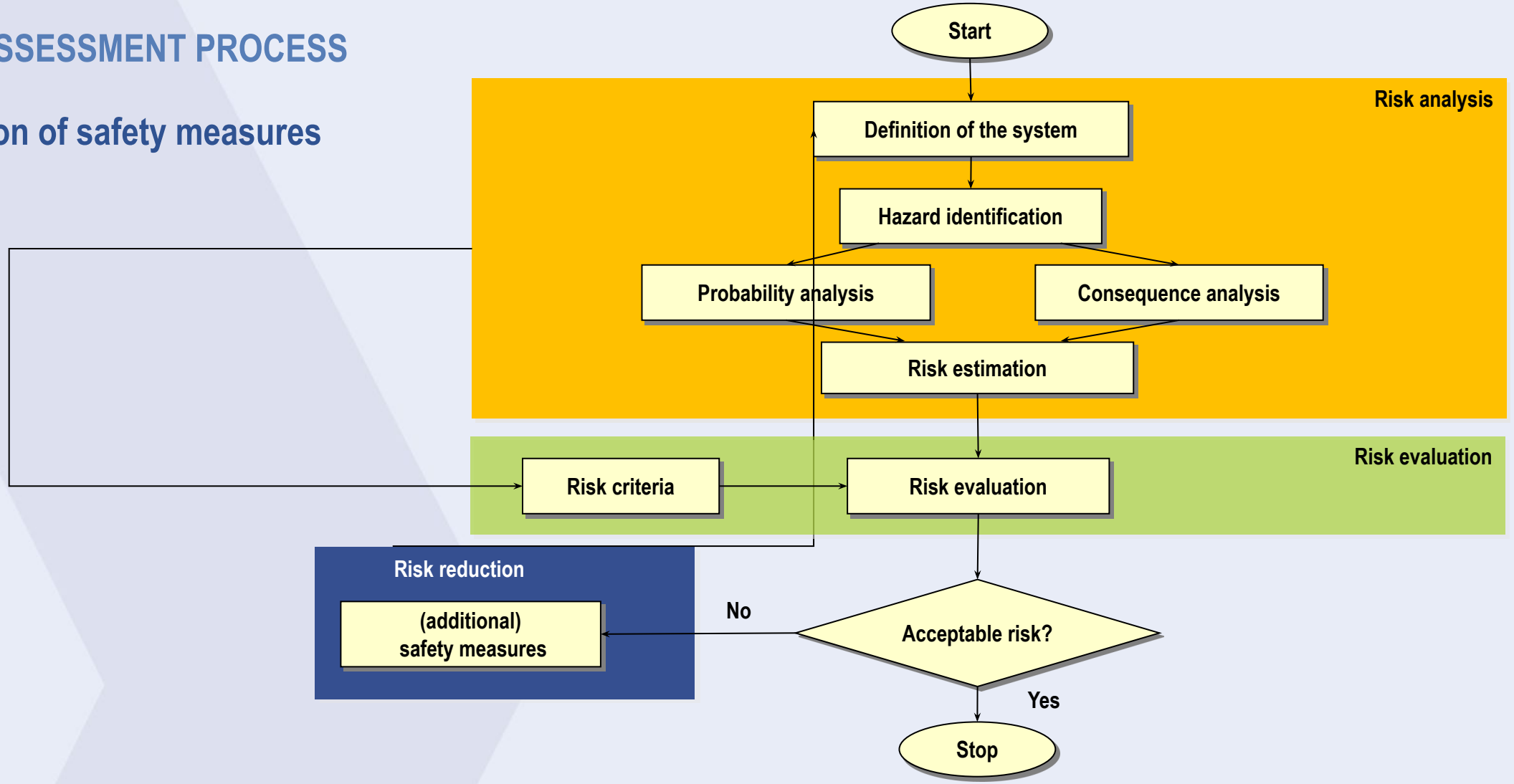
Implementation of tunnel safety into the life cycle of a tunnel

Combination of prescriptive and performance-based approach

HISTORICAL REVIEW

RISK ASSESSMENT PROCESS

Evaluation of safety measures



HISTORICAL REVIEW

20 YEARS AFTER TAUERN & MONT-BLANC FIRES

- Requirements of the EC-Directive have been implemented in Europe
  - in national legislation & regulation
  - in the internal rules of tunnel owners and operators
- The new organizational roles (tunnel manager, administrative authorities …) and the interaction of the various bodies are well established
- There is an increased awareness of tunnel managers & operators with respect to tunnel safety topics and their complexity
- Therefor there is a much more systematic approach, making use of sophisticated tools like quantitative risk assessment for risk-based decision making

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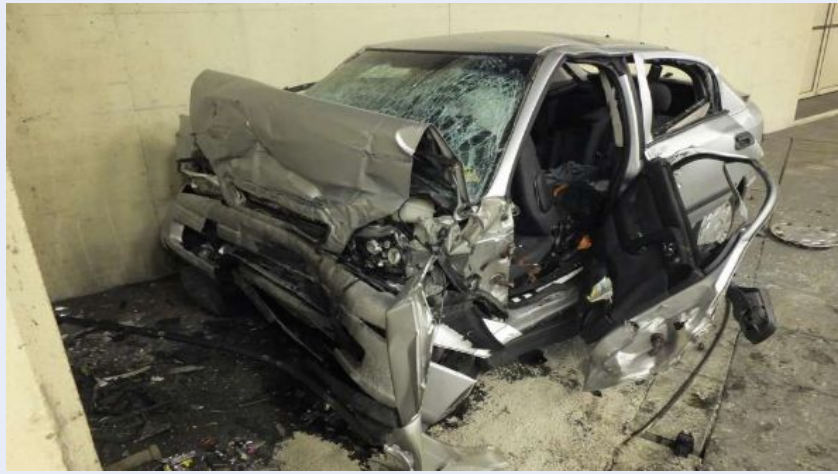
TUNNEL RISK ASSESSMENT - PRINCIPLES

BACKGROUND OF PERFORMANCE - BASED APPROACH

- Take a realistic view – acknowledge that risk is never zero!
- Take a closer look to address this risk
  - analyse functional interdependencies
  - quantify as much as possible – use historical data, technical parameters of tunnel system, traffic data, fill gaps by expert judgement
  - build a realistic model of the tunnel
- Important to know: calculated risk figures are not “real” in a sense that they predict what will happen!
- Instead, they show a representative picture of
  - what can happen
  - how often
  - and what can be the consequences


source Bericht BFI Landeck



RISK-BASED DECISION MAKING – PRINCIPLES

WHY DO WE NEED RISK-BASED DECISION-MAKING?

- For design decisions in planning phase (tunnel structure & equipment) of new tunnels
- To decide on safety requirements for upgrading of existing tunnels
- For decisions on additional risk mitigation measures (in case of deviation from prescriptive requirements, to compensate specific characteristics etc.)
- To select the best suitable combination of risk mitigation measures by combining results of risk assessment with cost-effectiveness analysis
- To decide on operational strategies for emergencies (operation of ventilation, traffic management etc.)
- To demonstrate a sufficient level of safety
  - In case of deviation from prescriptive requirements
  - In exceptional situations with a reduced safety level (e.g. construction phase of upgrading of existing tunnels)


source ASFiNAG

Tunnel du Lioran; source: CETU

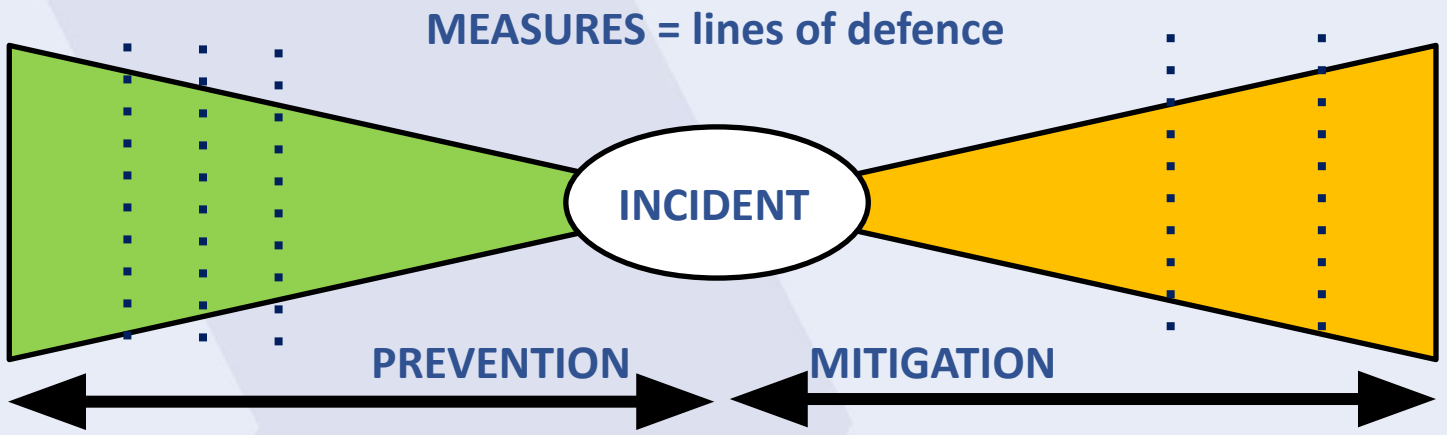
RISK-BASED DECISION MAKING – PRINCIPLES

ASSESSMENT OF SAFETY MEASURES

Tools for risk-based decision making – Quantitative tunnel risk model

4 Risk model **must be capable of** quantifying the effects of risk-mitigation measures on tunnel safety

- by modelling the influence of a specific measure on the functionality of a specific tunnel safety feature
- at each individual influence point in the chain of events



4 The quality of a tool depends on

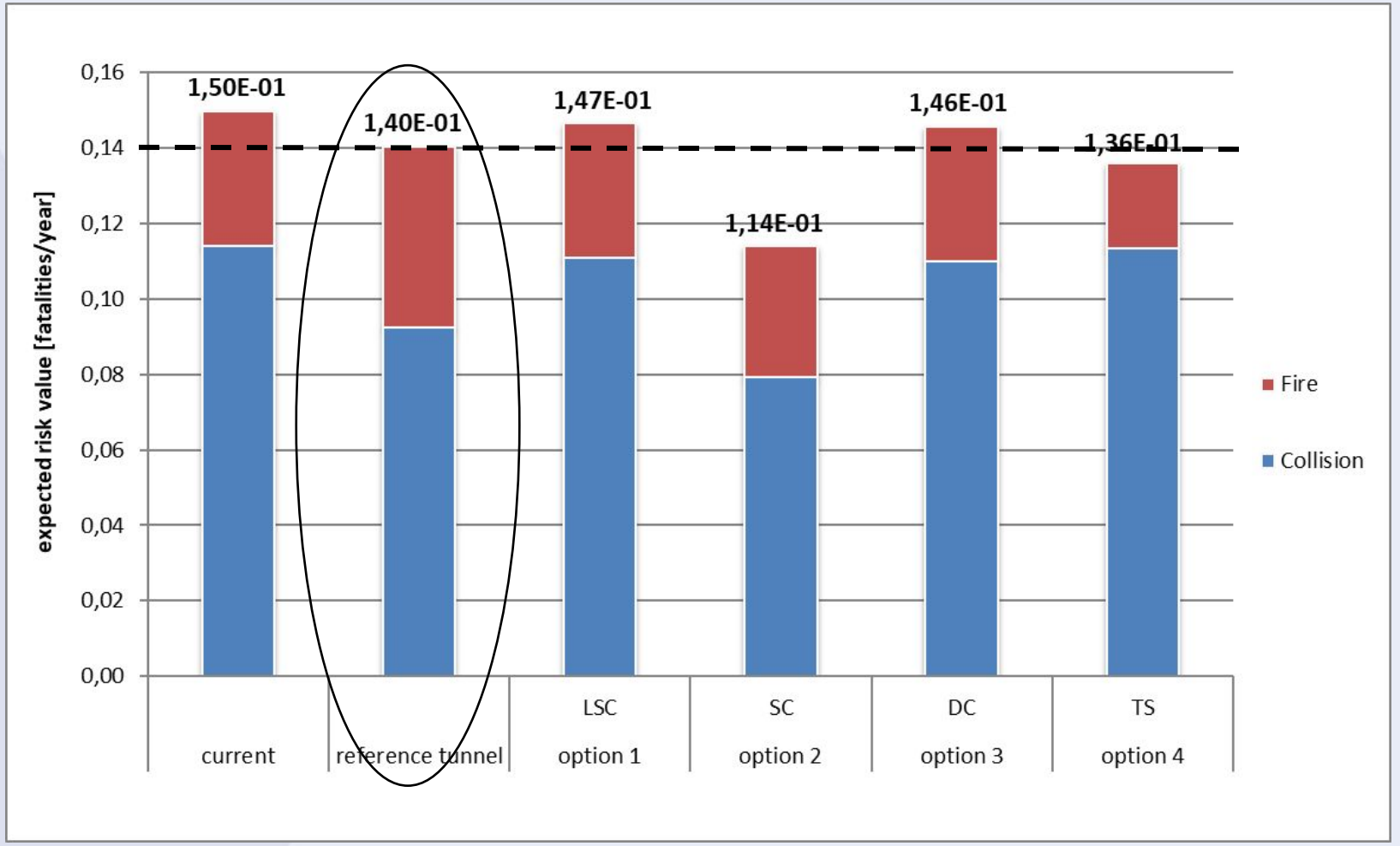
- The suitability for a specific problem
- The availability and quality of input data

RISK-BASED DECISION MAKING – PRINCIPLES

RISK EVALUATION – PRINCIPLE

Universally applicable Decision Making Principle:

Relative Comparison to Reference Risk Profile



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RISK-BASED DECISION MAKING – TOOLS

ILLUSTRATION OF METHODICAL APPROACH - EXAMPLE: AUSTRIAN TUNNEL RISK MODEL

Frequency analysis – Relevant parameters

Incident types
Traffic volume
Incident rates
Traffic composition
Ignition
vehicle categories

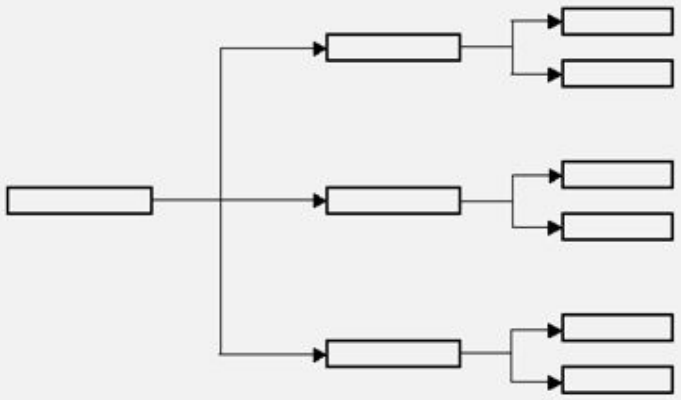
Consequence analysis – Relevant parameters

Tunnel system, technical systems, evacuation, vehicle categories

Results

Event tree

initial event → incident scenarios



X

mechanical accidents (statistics)

fires (model results)

RISK

Expected risk value (fatalities/year)

R

dangerous goods

fires

mechanical accidents

RISK-BASED DECISION MAKING – TOOLS

TuRisMo covers the complete range of significant tunnel incidents:

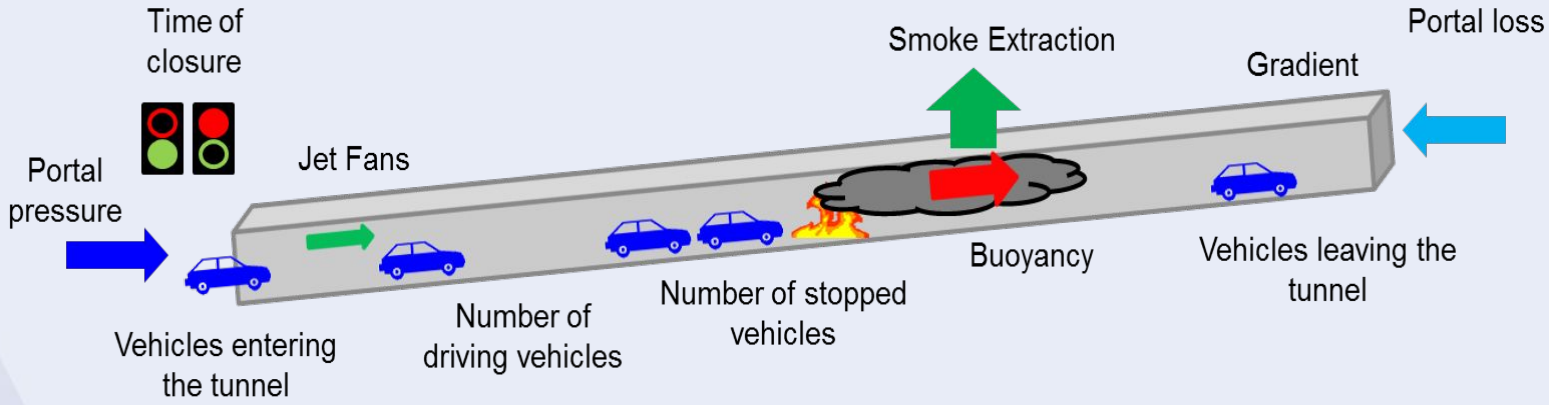
- **Frequency analysis – basic incident scenarios**
  - » Breakdown or malfunction of a vehicle causing a fire
  - » Breakdown or malfunction of a vehicle causing a collision (with or without fire)
  - » Single-vehicle collision (with or without fire)
  - » Different types of collisions between several vehicles (with or without fire)
- **Consequence analysis, fire – workflow for individual fire scenarios**
  - » Linear fire model defining fire growth up to maximum HRR (3 different model fires – 5 MW / 30 MW / 100 MW)
  - » 1-dimensional airflow simulation
  - » 3-dimensional airflow simulation
  - » Egress simulation: distances that can be walked in emergency conditions
  - » Exposure projection: fatality rate for assessed scenario – applying an accumulation-based intoxication model
- **To get a representative result, this process is repeated for all relevant fire scenarios –** depending on tunnel and traffic conditions

RISK-BASED DECISION MAKING – TOOLS

TuRisMo – CONSEQUENCE ANALYSIS, FIRE RISK, calculation of smoke propagation

For each detailed fire scenarios, a transient 1-dimensional airflow simulation is performed, taking into account all important influencing factors such as

- traffic movements
- fire location
- ventilation effects
- meteorological boundary conditions



The resulting global factors are applied as boundary conditions for a three-dimensional simulation of the local factors

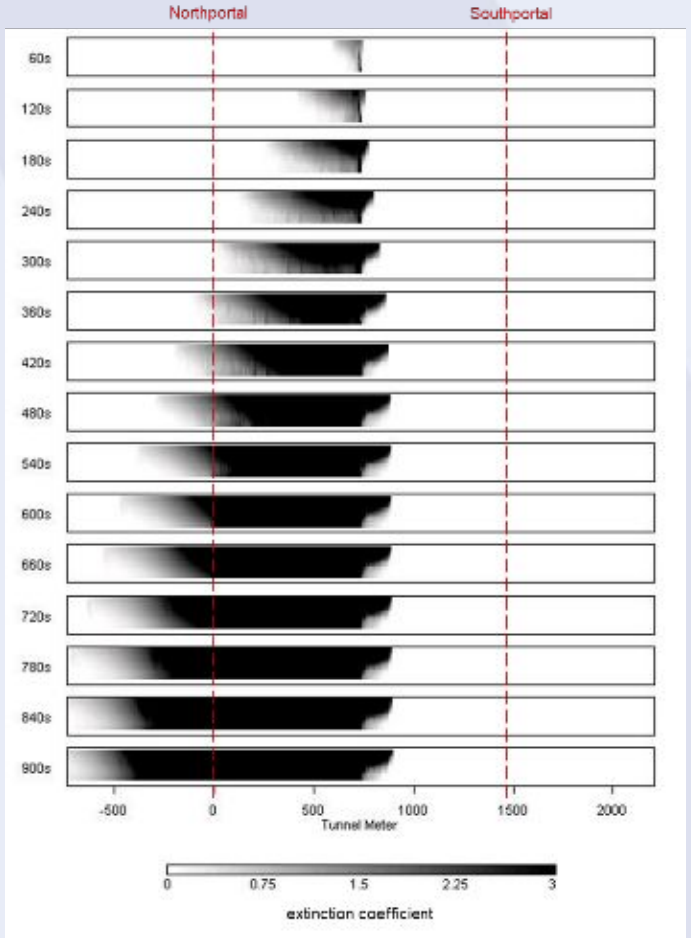
Thus the model is highly flexible and can be adapted to many different boundary conditions

RISK-BASED DECISION MAKING – TOOLS

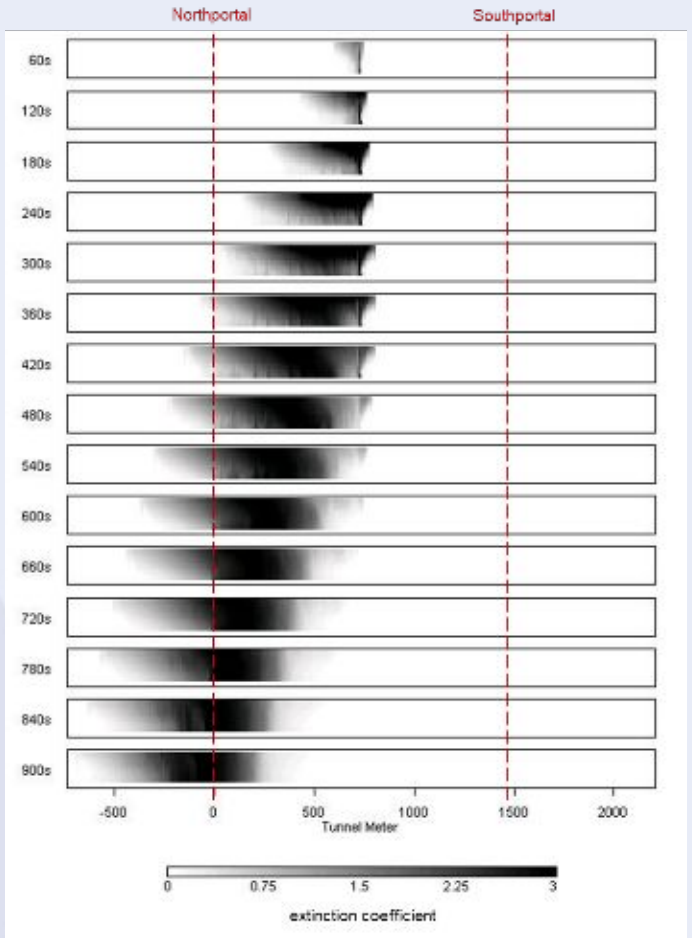
Evaluation of Measures: detailed and global results

Example: Bidirectional tunnel with longitudinal ventilation

Smoke propagation - without measures



Measure: fire brigade close to tunnel portal



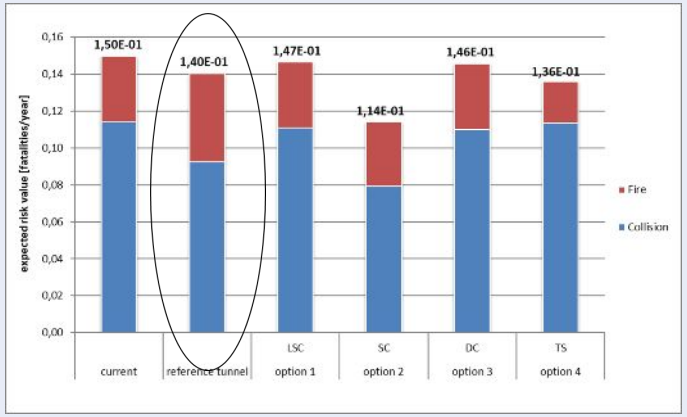


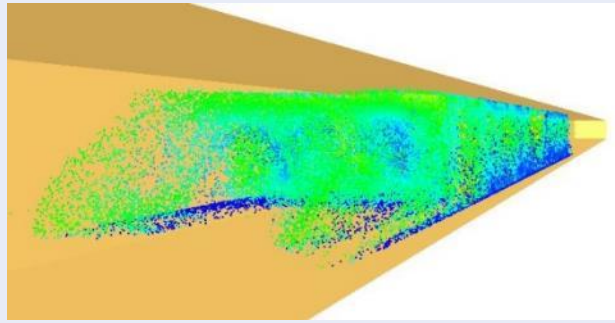
Diagram showing effects on global risk value

RISK-BASED DECISION MAKING – TOOLS

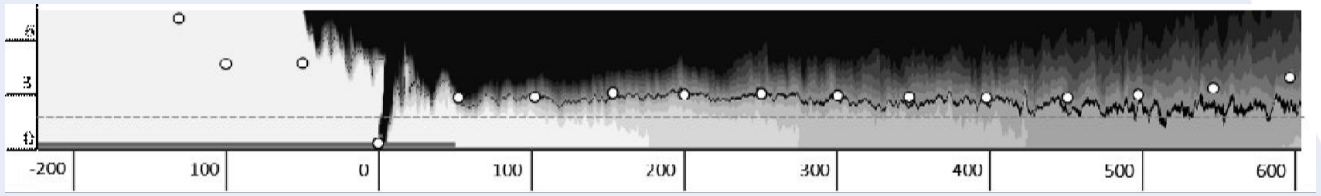
THEORY & PRACTICE – HOW RELIABLE ARE OUR TOOLS?

- **Complex risk mitigation measures like FFFS influence smoke propagation behaviour**
  - ⇨ Model predictions were compared to measurements of real scale tests (research project in Japan)

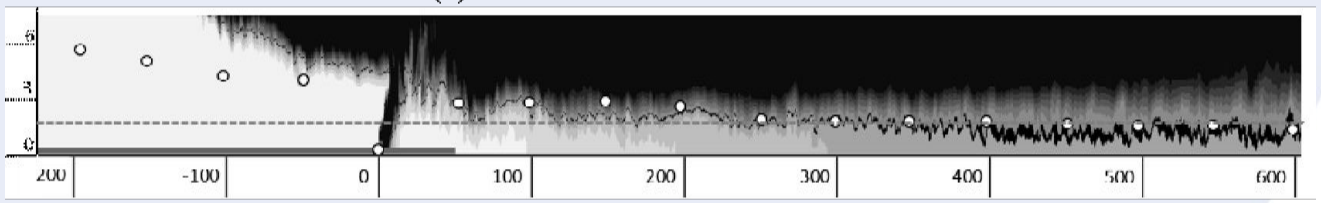
real scale fire test including FFFS activation



FDS model of fixed fire fighting system



(c) 6 minutes after fire occurred



(d) 12 minutes after fire occurred

Comparison of smoke layer height between real scale test including FFFS activation (white cirlces) and FDS model prediction (black surface)

RISK-BASED DECISION MAKING – TOOLS

NEW DEVELOPMENTS – INFLUENCE OF NEC VEHICLES

Decarbonisation of transport sector - accelerates replacement of fossil fuels - This brings new hazards into road tunnels

Several research projects investigated physical consequences of NEC vehicles involved in tunnel incidents – including real size testing

Relevant research projects:

- FFG - BRAFA - effects of fires in vehicles with alternative propulsion systems, 2019
- BAST - Impact of vehicles with new energy carrier technologies on tunnel safety - FE 15.0675/2020/ERB
- BAST - Review of assumptions and parameters for performing risk analysis for road tunnels (FE 15.0663/2019/ERB)
- FFG - HyTRA – Hyrogen Tunnel Risk Assessment (ongoing)

RISK-BASED DECISION MAKING – TOOLS

NEW DEVELOPMENTS – INFLUENCE OF NEC VEHICLES

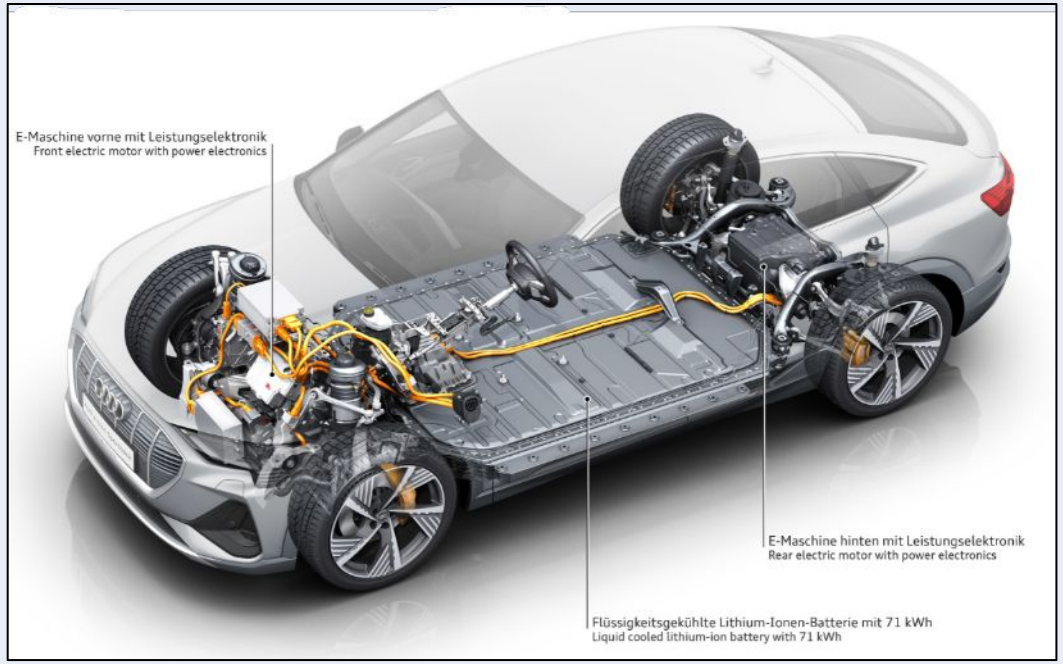
Energy carrier: Li-Io Battery

What can happen ?

- Main concern: Thermal runaway in battery is causing a fire, releasing extremely toxic gases (like HF, HCl)
- Future changes of risk profile to be expected - due to dynamic development in battery technology (construction type as well as chemism)
- Insufficient data to assess fire rates for BEV – probably lower than for ICE

Scenarios:

- Technical failure causing a fire in vehicle body (slow fire growth), triggering a delayed thermal runaway of battery
- Damage of battery as consequence of collision - causing a thermal runaway

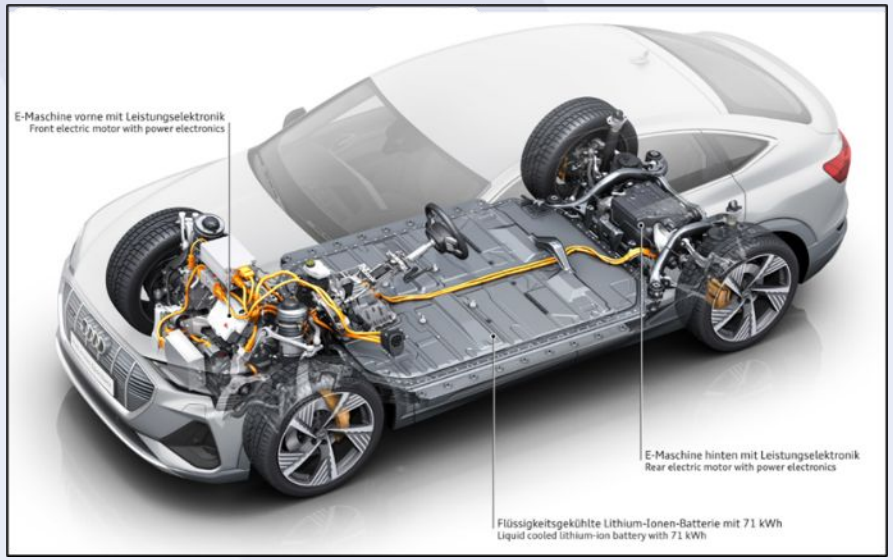


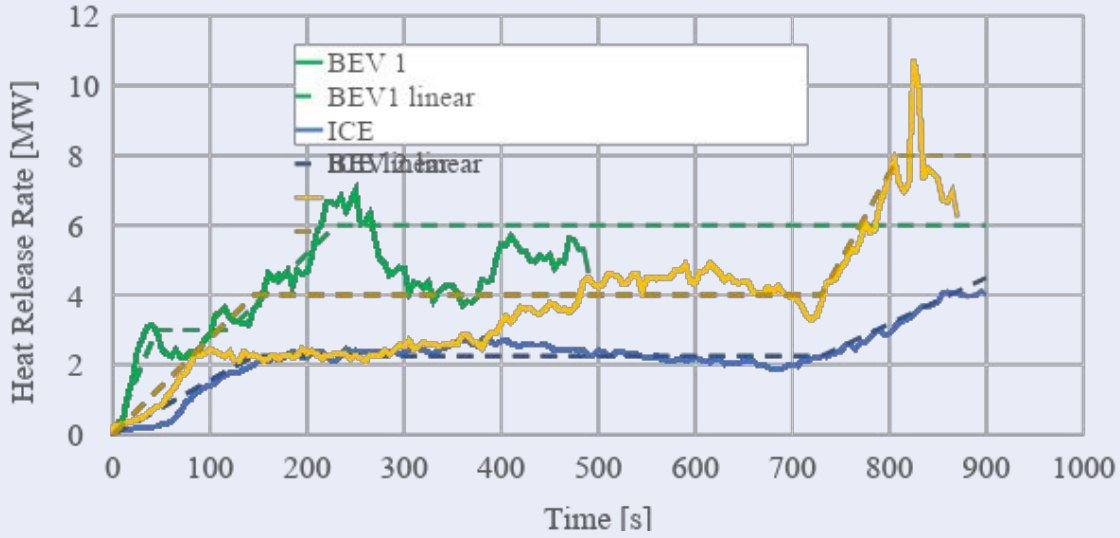
Quelle: AUDI AG, „Audi e-tron Sportback 55 quattro, Electric Drivetrain“

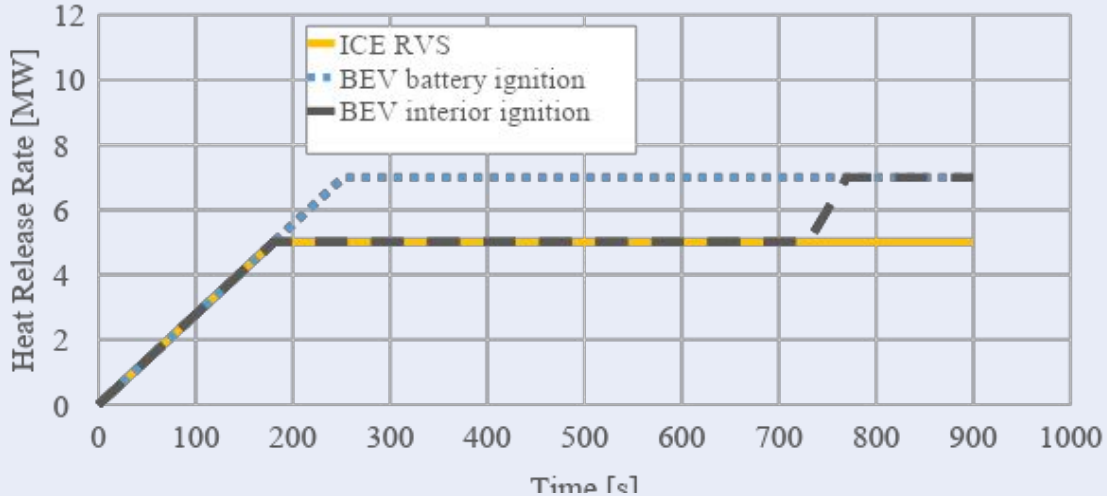
RISK-BASED DECISION MAKING – TOOLS

NEW DEVELOPMENTS – INFLUENCE OF NEC VEHICLES

Results from BRAFA fire tests: **Fire curve for BEV**







Conclusion for risk modelling: fire curves for BEV (e.g. for Austrian Tunnel Risk Model)

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RECENT PIARC ACTIVITIES IN TUNNEL SAFETY

RECENT PIARC PUBLICATIONS, PRODUCED BY WG2

- Risk Analysis for Road Tunnels
  (Report 2008 R02)
- Assessing & Improving Safety in Existing Road Tunnels
  (Report 2012 R20)
- Current Practice for Risk Evaluation for Road Tunnels
  (Report 2012 R23)
- Experience with Significant Incidents in Road Tunnels
  (Report 2017 R35)
- Prevention & Mitigation of Tunnel Related Collisions
  (Report 2019 R03)

4 Most recent publication:
Improving Road Tunnel Resilience –
literature study & case studies

All reports can be downloaded for free from the PIARC virtual library www.piarc.org

CONCLUSIONS & OUTLOOK

- **European road tunnels already have a high safety level - due to the implementation of measures of EU-Directive on Road Tunnel Safety**
  - » (Further) improvements of tunnel safety are often (very) cost-intensive - focus on a few, often extreme scenarios may result in an unbalanced safety level and disproportionate cost
  - » In most cases there are different options to reach a safety goal
  - » There is an increasing need for informed decisions - therefore a rational basis for complex decisions on tunnel safety is required

Advanced risk models provide a wide range of options to support informed decision-making

- **Range of application is continuously expanded by**
  - » feedback from experience,
  - » evaluation of incident data,
  - » implementation of new features (e.g. fixed fire fighting systems)
  - » ongoing research (e.g.modelling of effects of new propulsion technologies, extension to complex tunnel systems ...)

THANK YOU FOR YOUR ATTENTION!

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Greetings from