

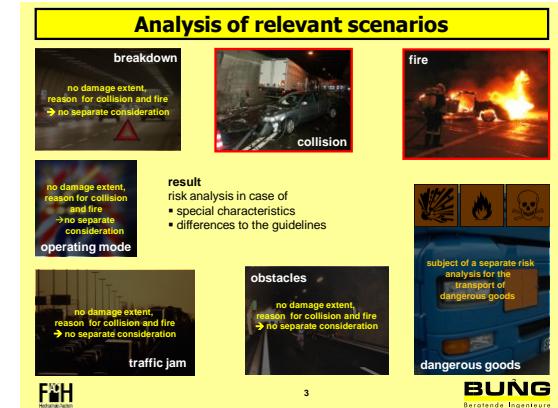
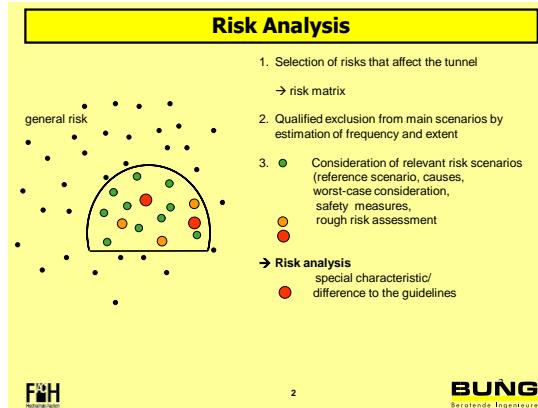
## Experience with Risk Analyses for Road Tunnels according to the EU-Directive and the German RABT

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**Operational Safety of Underground facilities**  
6. - 7. October 2009  
Istanbul



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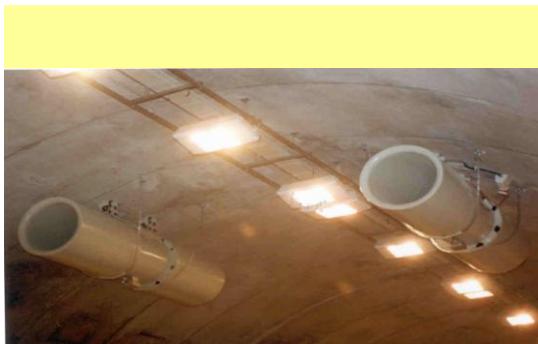
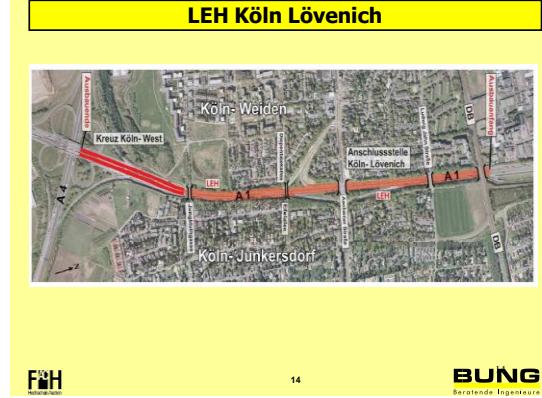
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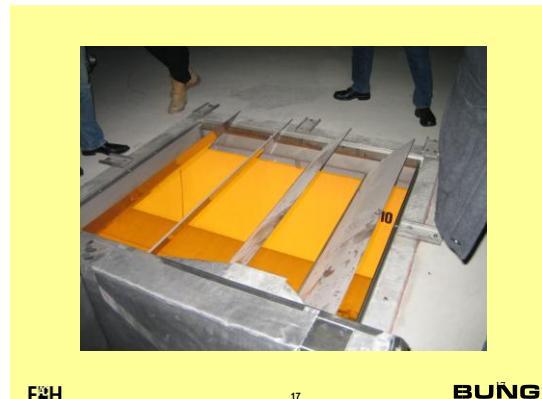
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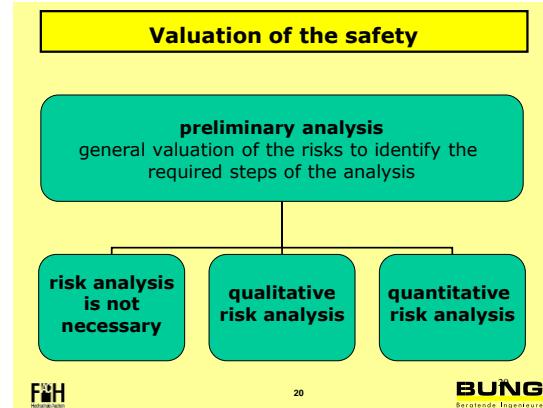
- Parameters for tunnel safety (EU-directive)**
- **tunnel length**
  - **number of tubes**
  - **number of lanes**
  - **cross-sectional geometry**
  - **vertical and horizontal alignment**
  - **type of construction**
  - **uni-directional or bi-directional traffic**
  - **traffic volume per tube**
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Parameters for tunnel safety (EU-directive)
> risk of congestion
> access time for the emergency services
> heavy good vehicles (%)
> dangerous goods vehicles (%), type)
> characteristics of the access roads
> lane width
> speed consideration
> geographical and meteorological environment

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Preliminary analysis
<b>Risk factors</b> <ul style="list-style-type: none"> <li>&gt; operating mode BA</li> <li>&gt; tunnel length L</li> <li>&gt; volume of traffic DTV<sub>R</sub></li> <li>&gt; proportion of heavy traffic α<sub>sv</sub></li> <li>&gt; proportion of congestion α<sub>congestion</sub></li> <li>&gt; effect of junctions ZA</li> <li>&gt; longitudinal gradient φ</li> <li>&gt; fire ventilation system BL</li> <li>&gt; distance between emergency exits d<sub>Emergency Exit</sub></li> </ul>

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Preliminary analysis
$K_{\text{collision}} = N_{\text{collision(BA)}} \cdot \sum_i (L_i \cdot DTV_{R,i} \cdot h_{\text{collision}}(BA_i, ZA_i) \cdot f_1(\alpha_{SVi}) \cdot f_2(\alpha_{\text{congestion}}))$
$K_{\text{fire}} = N_{\text{fire(BA)}} \cdot \sum_i (L_i \cdot DTV_{R,i} \cdot h_{\text{fire}}(BA_i, ZA_i) \cdot g_1(\alpha_{SVi}) \cdot g_2(\alpha_{\text{congestion}}) \cdot g_3(L_i) \cdot g_4(\phi_i) \cdot g_5(BL_i) \cdot g_6(d_{\text{emergency-exit}}))$

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Preliminary analysis						
<b>Valuation of the special characteristic</b> <table border="1"> <tr> <td><math>K \geq 1</math></td> <td>⇒ quantitative valuation of the safety</td> </tr> <tr> <td><math>1 &gt; K \geq 0.7</math></td> <td>⇒ qualitative valuation of the safety</td> </tr> <tr> <td><math>K &lt; 0.7</math></td> <td>⇒ no further valuation of the safety</td> </tr> </table>	$K \geq 1$	⇒ quantitative valuation of the safety	$1 > K \geq 0.7$	⇒ qualitative valuation of the safety	$K < 0.7$	⇒ no further valuation of the safety
$K \geq 1$	⇒ quantitative valuation of the safety					
$1 > K \geq 0.7$	⇒ qualitative valuation of the safety					
$K < 0.7$	⇒ no further valuation of the safety					

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Preliminary analysis						
<b>Valuation in the case of differences to the guidelines</b> <table border="1"> <tr> <td><math>100 * (K_{\text{Planfall}} - K_{\text{RABT}}) \geq 3</math></td> <td>⇒ quantitative valuation of the safety</td> </tr> <tr> <td><math>3 &gt; 100 * (K_{\text{Planfall}} - K_{\text{RABT}}) \geq 1.5</math></td> <td>⇒ qualitative valuation of the safety</td> </tr> <tr> <td><math>100 * (K_{\text{Planfall}} - K_{\text{RABT}}) &lt; 1.5</math></td> <td>⇒ no further valuation of the safety</td> </tr> </table>	$100 * (K_{\text{Planfall}} - K_{\text{RABT}}) \geq 3$	⇒ quantitative valuation of the safety	$3 > 100 * (K_{\text{Planfall}} - K_{\text{RABT}}) \geq 1.5$	⇒ qualitative valuation of the safety	$100 * (K_{\text{Planfall}} - K_{\text{RABT}}) < 1.5$	⇒ no further valuation of the safety
$100 * (K_{\text{Planfall}} - K_{\text{RABT}}) \geq 3$	⇒ quantitative valuation of the safety					
$3 > 100 * (K_{\text{Planfall}} - K_{\text{RABT}}) \geq 1.5$	⇒ qualitative valuation of the safety					
$100 * (K_{\text{Planfall}} - K_{\text{RABT}}) < 1.5$	⇒ no further valuation of the safety					

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### Example of the preliminary analysis

#### Tunnel Dortmund A 40

##### characteristics:

operating mode	one-way traffic
length	1957 m
volume of traffic	35.000 veh/d u. tube
proportion of heavy traffic	16 %
proportion of congestion	30 h/a => 0.4 %
effect of junctions	yes
longitudinal gradient	+/- 2.03 %
fire ventilation system	longitudinal ventilation
distance between emergency exits	200 m

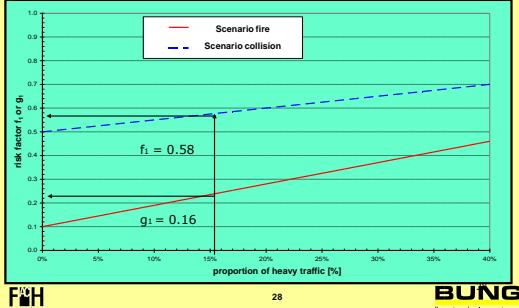


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### Example of the preliminary analysis

#### Risk factor „proportion of heavy traffic“



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### Example of the preliminary analysis

factor for standardisation	value of N
$N_{\text{collision}}$ two way traffic	64.2
$N_{\text{collision}}$ one way traffic	32.1
$N_{\text{fire}}$ two way traffic	$3.77 \cdot 10^4$
$N_{\text{fire}}$ one way traffic	$4.40 \cdot 10^3$



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### Example of the preliminary analysis

operating mode / effect of junctions	value of $h_{\text{collision}}$
two way tunnel with junctions	$9.81 \cdot 10^{-7}$
two way tunnel without junctions	$6.81 \cdot 10^{-7}$
one way tunnel with junctions	$5.28 \cdot 10^{-7}$
one way tunnel without junctions	$2.28 \cdot 10^{-7}$

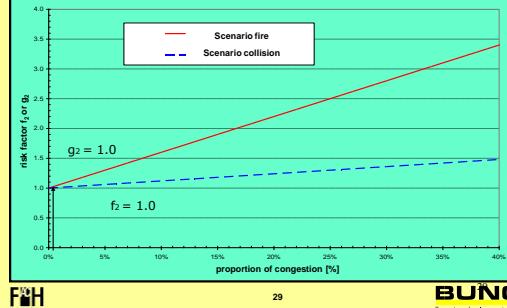


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### Example of the preliminary analysis

#### Risk factor „proportion of congestion“

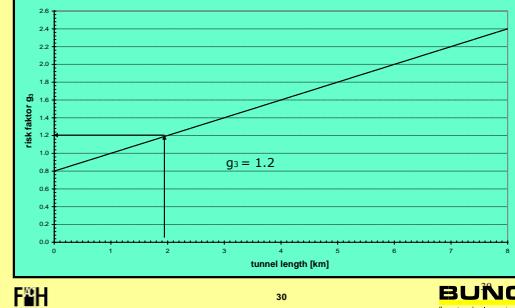


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### Example of the preliminary analysis

#### Risk factor „tunnel length“

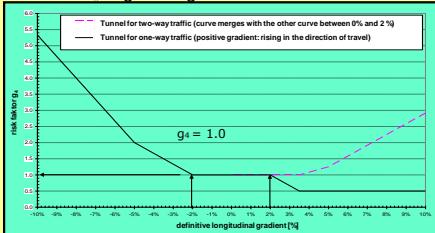


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### Example of the preliminary analysis

Risk factor „longitudinal gradient“



$$S = 0.145 \times 4.5 + 0.243 \times 0.5 + 0.162 \times 1.34 + 0.30 \times 0.98 + 0.15 \times 5.0 = 2.03 \%$$



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### Example of the preliminary analysis

Fire ventilation system

value of  $g_5$

Natural ventilation	4
mechanical longitudinal ventilation (smoke extraction through the portals)	1
Smoke extraction with exhaust air duct	0.5

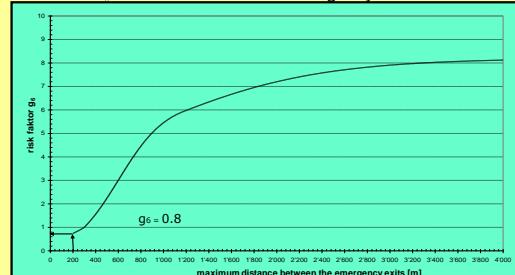


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### Example of the preliminary analysis

Risk factor „distance between the emergency exits“



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### Example of the preliminary analysis

value of risk „Tunnel Dortmund A 40“

$$\begin{aligned} \text{Collision} \quad K &= 32.1 \times 1.957 \times 35000 \\ &\quad \times 5.28 \text{ E-7} \times 0.58 \times 1.0 \\ &= 0.67 \end{aligned}$$

$$\begin{aligned} \text{Fire} \quad K &= 4.40 \text{ E+3} \times 1.957 \times 35000 \\ &\quad \times 4.58 \text{ E-9} \times 0.26 \times 1.0 \times 1.2 \\ &\quad \times 1.0 \times 1.0 \times 0.8 = 0.34 \end{aligned}$$

tunnel with two tubes

$$\begin{aligned} K_{\text{collision}} &= 2 \times 0.67 = 1.34 \Rightarrow \text{quantitative RA} \\ K_{\text{fire}} &= 2 \times 0.34 = 0.68 \end{aligned}$$



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### Example of the preliminary analysis

two-way tunnel

characteristics:

operating mode	two-way traffic
length	900 m
volume of traffic	20.000 veh/d
proportion of heavy traffic	10 %
proportion of congestion	30 h/a => 0.4 %
effect of junctions	no
longitudinal gradient	+ 3 %
fire ventilation system	longitudinal ventilation
distance between emergency exits	300 m



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### Example of the preliminary analysis

value of risk

$$\begin{aligned} K_{\text{collision}} &= 0.43 < 0.7 \\ K_{\text{fire}} &= 0.32 < 0.7 \\ \Rightarrow \text{risk analysis is not necessary} \end{aligned}$$



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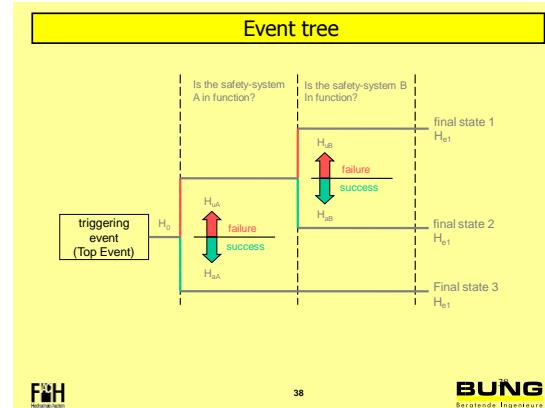
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## Quantitative Risk Analysis



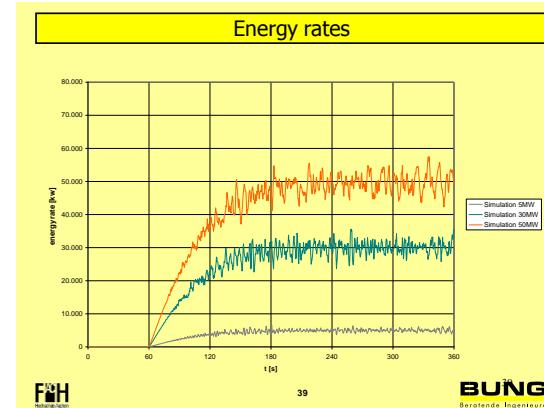
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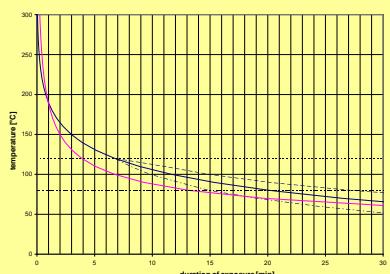
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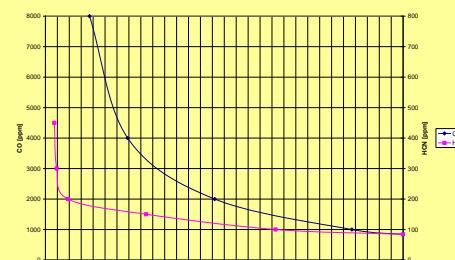
## Lethality because of temperature



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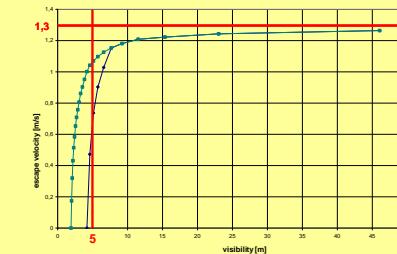
## Lethality because of CO- or HCN-exposition



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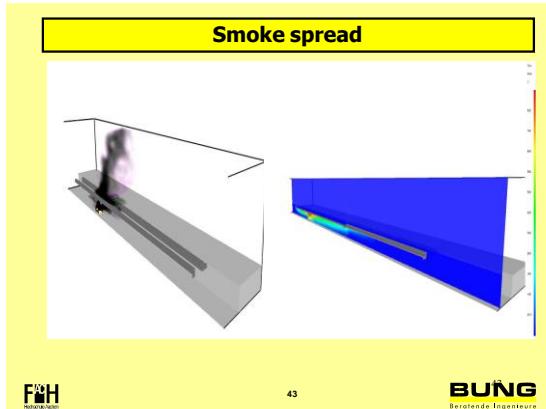
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## Correlation between visibility and escape velocity



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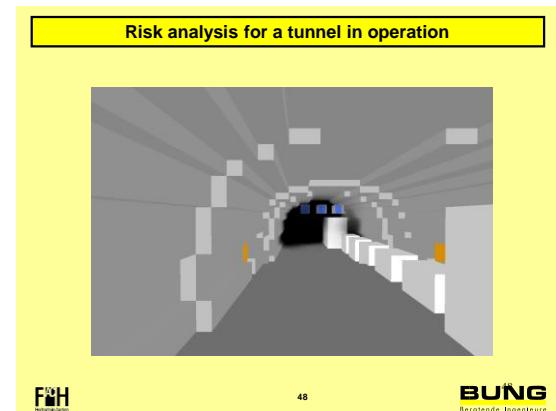
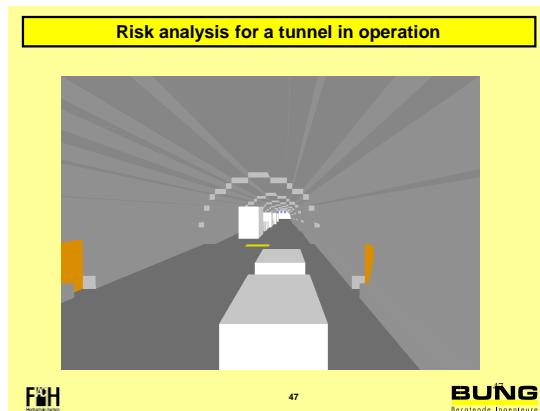
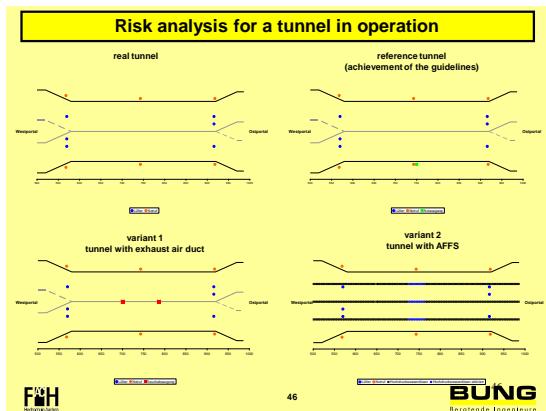
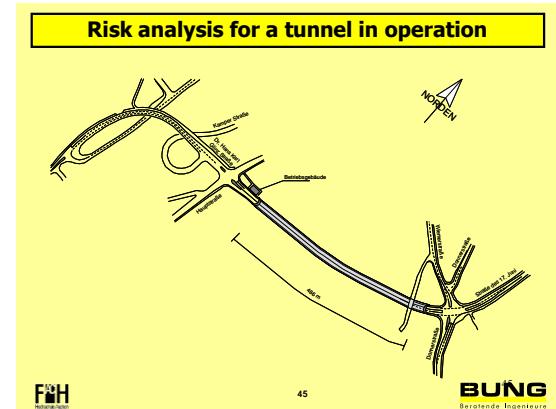


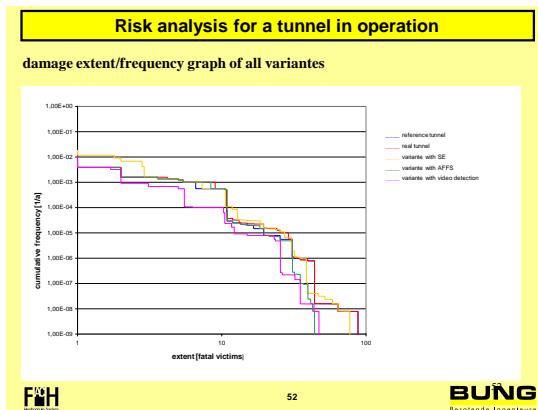
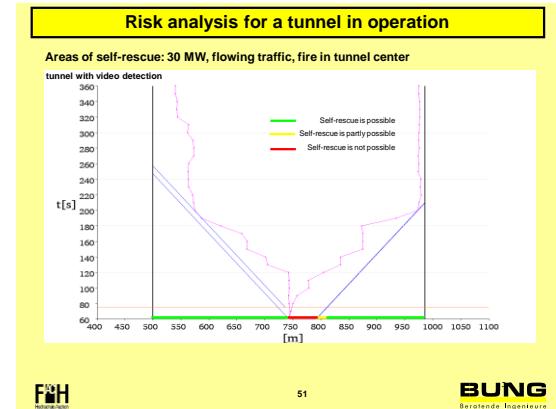
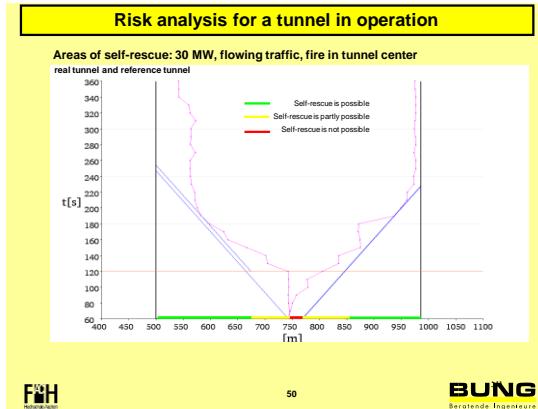
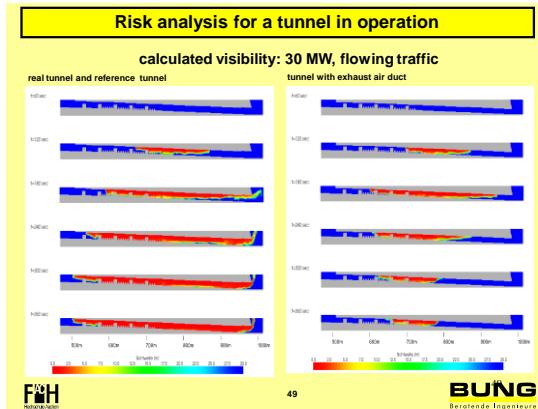
**Example**  
**Quantitative Risk Analysis**  
**Tunnel in Operation**

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**Risk analysis for a tunnel in operation**

	measure	costs	value of risk (fatal victims in case of fire)	value of risk (fatal victims in case of fire and collision)	level of safety in relation to the guidelines	
					fire	fire and collision
reference tunnel	emergency exit	1 800 000 €	0.017	0.029	-	-
real tunnel	-	-	0.019	0.031	-10.5 %	-6.0 %
variante 1	smoke extraction	2 000 000 €	0.031	0.044	-87.5 %	-49.6 %
variant 2	automatic fire fighting system	600 000 €	0.018	0.030	-7.6 %	-4.3 %
variant 3	video detection	250 000 €	0.008	0.021	+48.2 %	+27.4 %

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**Example**  
**Quantitative Risk Analysis**  
**Tunnel at Design Stage**

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### Risk analysis for a tunnel at a design stage

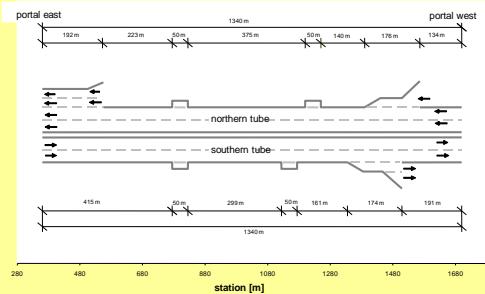


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### Risk analysis for a tunnel at a design stage

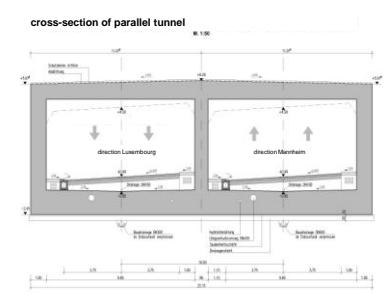


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### Risk analysis for a tunnel at a design stage

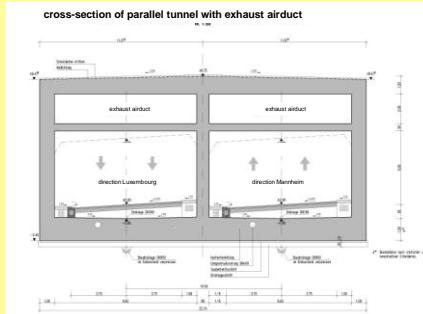


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### Risk analysis for a tunnel at a design stage

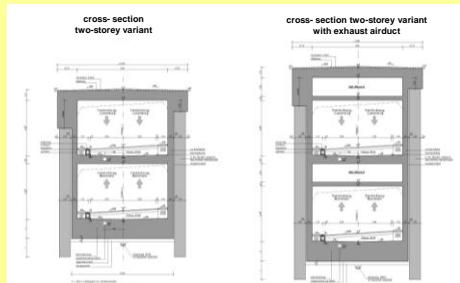


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### Risk analysis for a tunnel at a design stage

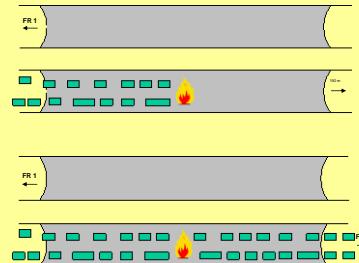


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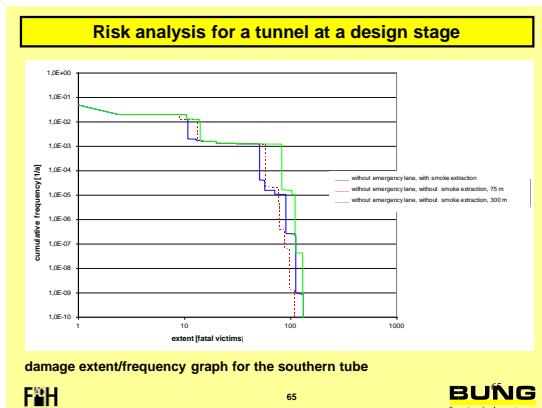
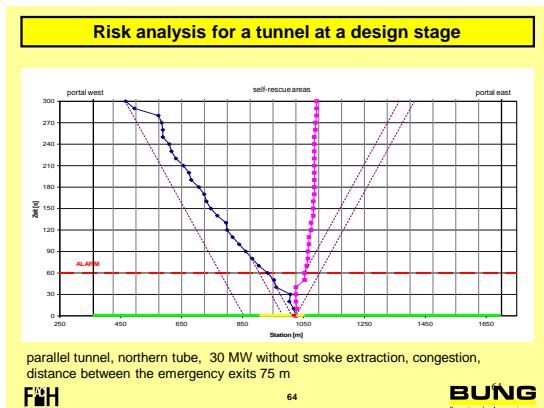
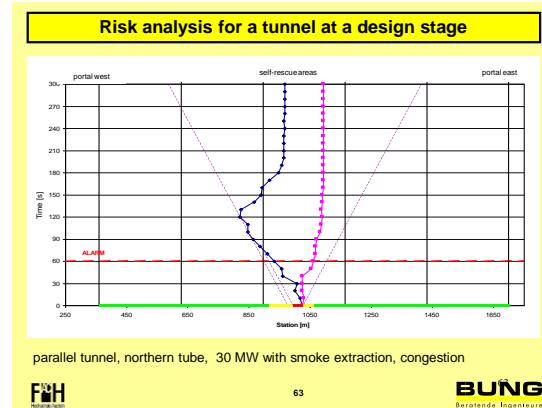
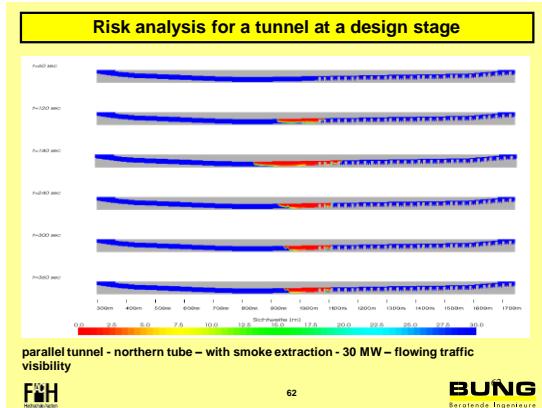
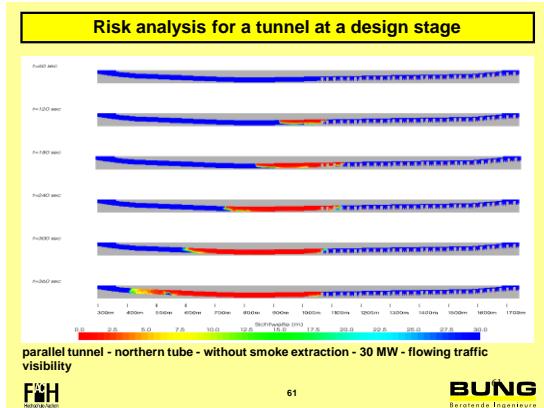
### Risk analysis for a tunnel at a design stage



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**Risk analysis for a tunnel at a design stage**

	tube	emergency lane	smoke exhaust airduct	distance between the emergency exits	value of risk	Level of safety in relation to the guidelines
parallel tunnel	northern tube	without	with	300 m	0.31	-
			without	300 m	0.35	-17.7 %
		with	75 m	0.28	+ 8.5 %	
	southern tube	without	with	300 m	0.26	-
			without	300 m	0.34	-27.8 %
		with	75 m	0.29	-10.3 %	
two-storey tunnel	northern tube	with	with	300 m	0.23	+ 29.1 %
			without	300 m	0.28	+ 10.9 %
		without	with	300 m	0.32	-
			without	300 m	0.35	- 9.4 %
	southern tube	with	with	300 m	0.22	+ 26.8 %
		without	with	300 m	0.24	+ 22.6 %
		with	without	300 m	0.31	-
		without	without	300 m	0.35	- 14.7 %

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## Conclusion

Quantitative risk analysis make possible

- Valuation of tunnel variants at the design stage
- Valuation of tunnel in operation
- Valuation of measures
- Evaluation of costs and benefits

Requirement are the most accurate input data for

- technical equipment
- traffic and accident rates
- ventilation system and the regulation of the system



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