Evacuation in tunnel

human behaviour, tunnel ventilation and more...

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Human behaviour – in case of fire in a tunnel

General

1. Rational
2. Assisting / helping
3. No panic
4. Behave as usual
5. Accept instructions from person of authority (police, emergency service, ...
Egress phases (control centre) and egress steps (user)

Phases according to **reactions in control centre**

a) Detection phase: time to detect incident
b) Alarm phase: time to evaluate proper response
c) Action phase: time to activate response
d) Egress phase: time to evacuate all users

Egress steps see from the **users perspective**

Caught behind fire

Leave car

Start egress

Identify and use emergency exits

Out of tunnel

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**Step 1**

Realise incident

**Step 2**

Wait in or by car

**Step 3**

Move towards exit

**Step 4**

Exit tunnel

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Egress time

Alternative strategy: turn car and drive out of tunnel
### Human behaviour

<table>
<thead>
<tr>
<th>Position</th>
<th>Ideal behaviour</th>
<th>Condition</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Stop outside tunnel</td>
<td>No tunnel closure</td>
<td>~0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tunnel closure with barrier</td>
<td>~100%</td>
</tr>
<tr>
<td>B</td>
<td>Stop and evacuate by food</td>
<td>See smoke/fire</td>
<td>~10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>See smoke/fire and radio/sign info</td>
<td>~50%</td>
</tr>
<tr>
<td>C</td>
<td>Evacuate by food</td>
<td>See smoke/fire</td>
<td>~40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>See smoke/fire and radio/sign info</td>
<td>~50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Directions by person of authority</td>
<td>~100%</td>
</tr>
<tr>
<td>D</td>
<td>Stop and evacuate by food</td>
<td>Captured in smoke</td>
<td>~30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Captured in smoke and radio/sign info</td>
<td>~40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Directions by person of authority</td>
<td>~100%</td>
</tr>
<tr>
<td>E</td>
<td>Drive out</td>
<td>No instructions to do otherwise</td>
<td>~100%</td>
</tr>
</tbody>
</table>
Typically, several minutes (2/3 of the total available egress time) is wasted during this step without the user moving anywhere.

It is difficult for the user to differentiate a fire from a normal traffic incident e.g. congestion and standstill.

Users often need information from different sources to realise that it is a critical situation.

There are large individual differences on which type and amount of information that is required.

Short and easy understandable messages are beneficial.
Human behaviour

Step 2: Decision making and preparation of egress

- The fires' potential growth rate is underestimated
- Several minutes can be used to discuss the situation with other users
- Some users start to extinguish the fire; but these stop doing so and commence evacuation if they feel that they are in danger
- Evacuation in groups, which extends the egress time
- Only evacuation through smoke, if users are convinced that this will lead them to an emergency exit

Realise incident

Wait in or by car

Step 2

Move towards exit

Exit tunnel

Step 1

Step 2

Step 3

Step 4
Improvement of Steps 1 and 2: Information

SLASS – Synchronised Longitudinal Announcement Speaker system

Realise incident
Step 1

Wait in or by car
Step 2

Move towards exit
Step 3

Exit tunnel
Step 4
Improvement of Steps 1 and 2: Information

SLASS – Synchronised Longitudinal Announcement Speaker system

t₀ = Audio Signal (undelayed)

\[ t₁ = t₀ + x \text{ milliseconds} \]
Improvement of control centre: detection and alarm phase

Reduce consequence by having a minimum tunnel ventilation at all times

Fire detection 600 sec @ 5MW and/or
Control centre/system reaction: 600sec

Always flow of ~1m/s in direction of traffic in unidirectional tunnels as mitigation measure for slow fire detection.

Fire detection 60 sec @ 5MW
Control centre / system reaction: 20sec
Reduction of sensitivity of speed of fire detection and reaction time by control centre

Improvement of control centre: detection and alarm phase
Reduce consequence by having a minimum tunnel ventilation at all times

rapid tunnel closure = minimise impact
Human behaviour

Step 3: move towards exit

- Tendency to **evacuate backwards from the way** that the user came from
- Tendency to **turn car** if **visibility** is **less than 10m**
- Users that have reached a safe haven are **prepared to re-enter the zone of danger**
- Egress speed 0.3m/s (no visibility) to 2m/s; mobility impaired down to 0.17m/s.
Bi-directional traffic

Snu og kør ut / turn car and drive out

- Assumption NordFou-project: 60 s to turn car
  Speed in smoke: 2 m/s = 7 km/t

- Alle cars could exit the tunnel without coming in a critical situation

- Problems:
  - Large vehicles cannot turn and hence blocks the passage for other cars
  - Collision with tunnel wall
  - Impact with user egressing by foot
Lights provides guidance and reduces risk of incidents

Guidance lights and illuminated egress signs

Step 1
Realise incident

Step 2
Wait in or by car

Step 3
Move towards exit

Step 4
Exit tunnel
Smoke management

Steps 1 to 3: how to gain time

- Smoke extraction
- Longitudinal ventilation (no cars/persons downstream)

Realise incident  
Step 1
Wait in or by car  
Step 2
Move towards exit  
Step 3
Exit tunnel  
Step 4
Smoke management when cars/persons on both sides of fire

Steps 1 to 3: how to gain time

- Smoke extraction, large distance between emergency exits

- Longitudinal ventilation, short distance between emergency exits and fixed fire fighting system

[Diagram showing step-by-step process with illustrations of vehicles and smoke]

Step 1: Realise incident

Step 2: Wait in or by car

Step 3: Move towards exit

Step 4: Exit tunnel
Tunnels with bi-directional traffic

Longitudinal ventilation: rapid activation and high speed is advantageous

- Short detection- and response time is important
- Ventilation reduces the effects
Smoke management in single-tube tunnel with bi-directional traffic

Which measures are efficient to minimise the potential fatalities?

Tunnels with one tube and bi-directional traffic:
- Often low equipment level
- Low traffic numbers
- Perhaps long
- Perhaps high longitudinal slopes
Smoke management in single-tube tunnel with bi-directional traffic

Longitudinal ventilation: equality, stratification and/or dilution?

Minimise speed of smoke spread, high CO concentrations: Japan

Reduce CO concentrations and retain favourable conditions for smoke stratification

Smoke spread only in one direction, smoke dilution: simple strategy
Human behaviour

Step 4: Exit tunnel

- Emergency egress are used, if the user have had positive experiences using emergency exits
Emergency exits

In case of ideal human behaviour a very efficient safety measure

- Optimal fire detection and response
- Late fire detection and late response

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**Fatalities**

- **50m**
  - Optimal fire detection and response: 1
  - Late fire detection and late response: 5

- **150m**
  - Optimal fire detection and response: 2
  - Late fire detection and late response: 15

- **250m**
  - Optimal fire detection and response: 10
  - Late fire detection and late response: 25

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**Distance between emergency exits**

**Step 1**

- **Realise incident**

**Step 2**

- **Wait in or by car**

**Step 3**

- **Move towards exit**

**Step 4**

- **Exit tunnel**
Egress doors

Visible egress doors (green with light around, easy to use (e.g. opening force > 100 N) also from a wheelchair

Step 1: Realise incident
Step 2: Wait in or by car
Step 3: Move towards exit
Step 4: Exit tunnel
Future technology

- Mobile phones
  - Detection
  - Information about congestion and traffic movements
  - Contact to users
- Alarm via eCall
- ITS, car to car and/or infrastructure communication
- IR Camera, radar detection
- Automated and autonomous cars

... and everything has to function as envisaged i.e. the minimal operation conditions need to be known

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Thank you – questions?