Human Factors Analysis of Underground Environmentsafe

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Outline

- Holistic view on human factors in underground environments
- Theoretical viewpoints
- Practical implementation
  - Examples from road tunnel design
  - Examples from design of underground parking
- Transferability to underground work environments
Psychological aspects of being underground

- A common problem with underground facilities for public use is the feeling of danger and entrapment they generate.
- Isolation and monotony are two common problems reported by employees in underground workplaces.

Sources:
Sommer 1974; Hollon, Kendall, Norsted & Watson 1980; Wada & Sagukawa 1990
Psychological aspects of working underground

- Lack of windows, isolated from outside (cannot see changes in outside view /greenery)
- Worried about physical health
- Mental stress & anxiety, Claustrophobic
- Worried about risk of fire
- Poor air quality
- Inappropriate layout & structure
- Oppressive atmosphere - ceilings feel low (even if same height as above ground)
- Job efficiency reduced
- Limited visibility – feel isolated
- Lack of visual stimulation - including greenery
- Do not like working underground
- Disorientated, Noisy. Visual fatigue
- Low job satisfaction linked with most complaints
- Not paid enough for working underground

Possible health problems deep underground

- **Mental health problems**: anxiety, reduced attention spans, depression, dissatisfaction, poor judgement, mental fatigue, stress, tension.

- **Physical health problems**: allergies, Alzheimer's disease, anaemia, asthma, arthritis, reduced attention span, high blood pressure, cancers, poor circulation, diabetes, eczema, fatigue, heart attacks, hypoxia, poor immune system, intestinal disorders, infertility, kidney problems, reduced lifespan, Multiple Sclerosis, obesity, osteoperosis, chronic pain, poor reaction times, respiratory disease, stomach diseases, strokes, tiredness, weakness.
Theoretical perspectives

- Eclectic
  - Behavioural theory (perceived control)
  - Ecological Psychology ("Context is king")
  - Sociotechnical Theory (Joint Cognitive systems)
Modern Behavioural Theory

Phobias result from:

1. Biological preparedness to fear and avoid certain stimuli
2. A learning episode strengthening the avoidance behaviour
3. degree of perceived control, has important modulating effects on phobic reactions.
4. limited possibility for escape can explain some aspects of the seemingly universal negative associations that underground space evokes.

Some of the consequences this theory have for design of underground facilities for work use are discussed.
Some examples of tunnel projects

- **Long tunnels**
  - The worlds longest tunnel – Lærdal (NPRA)
  - Taiwan tunnel project (Sub. to China Engineering)
  - China QZM tunnel project (Shaanxi Communication Bureau - Zhongnan Highway tunnel)
  - US Road/Rail tunnel, (Rocky Mountains, feasibility study)
  - The worlds longest twin tube tunnel (China - QZM Phase 2)
  - South Korea: State of the art (Transport Ministry)
  - Chile: Chuquicamata acess tunnel (Skava/Codelco)

- **Subsea Tunnels**
  - Rogfast 27 km subsea tunnel (NPRA)
  - South Korean sub sea tunnel (………)
  - Fehmarn belt (Sub to Cowi)

- **City tunnels**
  - Stockholm ring (Sub to Traficon)
  - Bjørvika Tunnel (NPRA)
  - Kristiansand City tunnel (NPRA)
  - LED lights in tunnels (NPRA Trondheim)

- **Evacuation strategies**
  - Evacuation strategies in tunnels (NPRA)
  - Dew problems in tunnels (NPRA)
  - Tunnel Stop-Lights for traffic management (NPRA)
  - UPTUN (European Commission)
  - **Tunnel Emergency Signs and Systems** (Texas transportation)
Qinling Zhognansan

One of ten longer than 10 km Worldwide

Kilde: Susanne K. Lund, Stockholm 2010
Introduction
– Longer and deeper tunnels
– Major part of city landscape

- Reducing travel time
- Connecting areas together
- Improving urban environment
- Risk of land slides
- Risk of avalanches
- Closed roads in winter
Not much research

Tunnel portals

- Energy Efficiency
- Design
Problems in tunnels

- Monotony
- Lack of daylight
- Lack of landmarks
- Lack of variation
- Lack of speed/distance, slope references
- Fear of entrapment
  - Lack of visible escape routes
    - Narrow
    - Wet
- Unpleasant catastrophic associations
  - Fire, Water, Cave in
Tunnel-Angst

Der Alptraum, den viele Autofahrer nicht wahrhaben wollen
Surveys – How people experience tunnels

- Road tunnels (Norwegian studies)
  - 15 % feel unpleasant/are afraid
  - 20 % feel anxious (50 % female)
  - 2-3% severe klaustrophobia

- Long road tunnels (Norway)
  - 30 % find it dangerous (20 % male, 40 % female, 45 % elderly)

- Sub sea tunnels
  - 7% would never drive (Norway)
  - 12 % negative (Norway)
  - 38 % in Denmark are afraid, (5 % refuses to drive through)

- Supported in Chinese, Swedish and Austrian surveys
Irrational fear?
Some serious lessons learnt from fires in road tunnels:

Mont Blanc (France-Italy) 1999 March 24: 39 persons died
Tauern (Austria) 1999 May 29: 12 persons died
St. Gotthard (Switzerland) 2001 Oct. 24: 11 persons died
Symptoms

- Stiffen (reduce speed)
- Dizzy
- Hyperventilation
- Uncontrolled shaking, freezing
- Sweat
- Hard grip around steering wheel
- Sudden evasive action
- Emergency braking
- Panic (High speed)
Example of anxiety and discomfort

- Had this anxiety since 1993, also in other settings.
- Can now cope with 2km tunnel alone, - if distance signs are shown / no que
- Have driven - 200km/h with hyperventilation, must rest an hour afterwards.
- No problems with same tunnel length in Spain, due to better visual standard, - brighter tunnels

Kjell Aasen, Bergen (Fireman)
Suveys – Conclusion

- Road tunnels have a considerable negative effect on road users feeling of safety and comfort

- Thus, there is a need for making the tunnels more attractive to the road users
Research examples
The Lærdal Tunnel, Norway (2001)

The world longest road tunnel: 24.5 km
### Countermeasure Analysis

<table>
<thead>
<tr>
<th>Problem</th>
<th>Human</th>
<th>Technology</th>
<th>Management</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow moving vehicles</td>
<td>Information</td>
<td>AID + Variable message sign</td>
<td>Information to road users, closing tunnel or lanes</td>
<td>Avoid curves</td>
</tr>
<tr>
<td>Slippery road</td>
<td>Information</td>
<td>Ice/friction detector Variable message sign</td>
<td></td>
<td>Materials/drenation</td>
</tr>
<tr>
<td>Narrow</td>
<td>increase lighting, or improve contrast</td>
<td></td>
<td></td>
<td>Increase tunnel height, road width, Perceptual illusions, Tunnel enlargements</td>
</tr>
<tr>
<td>Monotonous</td>
<td>variation in light intensity, radio channels available</td>
<td></td>
<td>Variation in measures over time</td>
<td>Tunnel enlargements dividing the tunnel, use of colors, art</td>
</tr>
<tr>
<td>Fear of entrapment</td>
<td>Information about turnaround possibilities</td>
<td>Sign indicating turnaround</td>
<td></td>
<td>Tunnel enlargement, turnaround</td>
</tr>
<tr>
<td>Loss of scenery</td>
<td>Information about alternative routes</td>
<td>Image projection</td>
<td></td>
<td>Tunnel enlargement with projection or picture of scenery</td>
</tr>
</tbody>
</table>
3 rock caverns

- Dividing the tunnel into 4 short tunnels to reduce monontony
Rock caverns
Design solutions
develop and test and optimize
4 alternatives tested in a driving simulator

Alt 1: ”Basic”

Alt 2: ”Water”

Alt 3: ”Rock Crystals”

Alt 4: ”Outdoor experiences”

Cavern 1

Cavern 2

Cavern 3
In depth analysis: Fatigue a serious problem

Human Error 95% of all road accidents

Fatigue 29-42%

*Undertermined either fatigue or acute impairment

“Inexplicable accidents. ICADTS, Stockholm
Avoid red and yellow colour combinations
Avoid large black unlit gaps
From idea to implementation

"Rock Crystals", Sketch

"Rock Crystals", Simulator

Implemented in the Lærdal Tunnel – "Rock Crystals"
Strategies for interior design and lighting have been a success.

- No accidents
- Massive media coverage
- Lighting awards

Good feedback from road users
A tourist attraction
Zhongnanshan Tunnel, China (2007)
The world longes twin tube tunnel: 18 km
Multidisciplinary project

Advisory role:

The first survey & design institute of the ministry of railways, Xi’an, China

Phase I - Third party evaluation

1. **Ventilation**  Skistad, SINTEF Energy

2. **Fire Safety**  Opstad, SINTEF Fire Lab. (NBL)

3. **Lighting Design**  Augdal SINTEF ICT

4. **Traffic Management**  Foss, SINTEF Transport Research

5. **Driver Behaviour & Safety**, Jenssen, SINTEF Transport Research
Evaluation

- To evaluate the fire safety issues in terms of possibilities of escape and to mitigate the fire and its consequences.

- To evaluate the quality of the plans for the traffic surveillance and management system.

- To evaluate the proposed principles of lighting and the energy saving issues.

- To evaluate the proposed ventilation system in terms of air quality, fire smoke venting as well as cost efficiency in operation.
The project

Phase II

1. Design (several aspects)

2. Simulator trials for increased safety and attractiveness

3. Rock Mechanics

4. Ventilation

5. Lighting
Director Qiao Huaiyu Shaanxi communication Bureau: QZM tunnel (left)
Project manager Wen Banghou Shaanxi communication Bureau: QZM tunnel (right)
Project manager Gunnar D. Jenssen SINTEF: Safety evaluation and Special lighting design (middle)
Qinling mountain ridge
Main inland highway north-south
3-D image of tunnel

Courtesy IPORY
3 rock caverns in each tunnel tube
Design solutions for "event zones"

Monotony, attractivity and safety

*Develop and test and optimize*

SINTEF Advanced Driving Simulator
Eye Tracking

![Eye Tracking Diagram]
Ranking – caverns, divided into nationality

A cultural difference

- Skyway – cavern 3 has a bad ranking among both Chinese and Norwegians
Instalation: Schenzen Glitter Electronics Ltd.
Breathing space in Chinese tunnel created by Norwegian artists designers
Developed and tested in the SINTEF driving simulator
Light Emitting Diodes (LED) to increase comfort and visual guidance

Seen as white with traffic flow and red if you drive against traffic
From idea to reality
Timetravel
“Time portal”

SOUTH GATE DAYTIME
“Time portal”

SOUTH GATE NIGHTTIME
Project manager Wen Banghou Shaanxi communication Bureau: QZM tunnel
Project manager Gunnar D. Jenssen SINTEF: Safety evaluation and Special lighting design
Tunnel entrance by night
Tunnel interior
Oslofjordtunnelen
14. april 1997
small dynamitt
og champagnekorker
i grustaket på

Storsand i Hurum. Anleggsstart for tunnelarbeidet på det som blir verdens lengste undersjøiske veitunnel var i gang.

1. juli 2000 kjører de første biler gjennom tunnelen.

**Urøm**

**Klerhet:**
svinnus: hele tunnelen blir det montert CO2-måler for tilsynlig overvåking av luftkvaliteten. Dersom
nsene oversvørs, blir dette varett ved innkjøring til
tunnelen. Det blir også montert sikringslåker.

**Egerslag:**
Hunnsiden tas masken ut via et overvåks, en adkomst-
het på 700 meter. Når tunnelen åpnes for trafikk, kan
se benyttes som rørøgningsvæske. Den går fra 2 mon-
hutte over en strømlinje på 700 meter (ca.12% huling)

**Tunnelen:**
Tunnelen får et fall på 7% ned.

**Vann:**
Vann som renner inn i tunnelen vil sjået, i tunnelen under Oslofjorden.

**Längder og fremskridtssøl**

<table>
<thead>
<tr>
<th>Anleggsparsee</th>
<th>Lengde (m)</th>
<th>Fremskridtssøl</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Kokkedal-Kongens dal</td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>3Kongens dal-Verpøen</td>
<td>4900</td>
<td></td>
</tr>
</tbody>
</table>
Idea:
“To remind road users of the sea above”

Disastrous for people with tunnel anxiety!
Tunnel Psychology
Need hierarchy

This is what makes the tunnel unique attractive and comfortable for all road users. Attract professionals, tourists, media.
Attractive Underground Parking Space

SINTEF Technology & Society

Project owner: Giertsen Tunnel AS
Site vitis national & international
Underground parking Oslo
Underground parking
Santiago Chile
Med dukt
Utsiden-inn Blå
Utsiden-Inn Strand
Utsiden-Inn Blå strand
Med duk
(utsiden-inn)
Mood lighting

- lighting solution for aircraft cabins
- The solution combines white light with mood light in one system,
- Using True Colour Stabilisation (TCS) technology to offer unique light presentation
Råberg
(sprøytebetong)
Design process
From idea to reality
Is methodology knowledge and design solutions relevant for underground work environments
Comparative analysis

- Road tunnels are deep underground or subsea
  - Public fear and anxiety
  - Length
  - Depth
  - Speed
  - Time spent
Comparative analysis

- Underground Parking
  - Public fear and anxiety
  - Depth
  - Speed
  - Time spent
## Human factors of underground Road tunnels vs workspace

<table>
<thead>
<tr>
<th>Factors</th>
<th>Problem</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar</td>
<td>Yes (lack of landscape)</td>
<td>Yes (illusions)</td>
</tr>
<tr>
<td></td>
<td>Yes (fear – no way out)</td>
<td>No (orient./ escape)</td>
</tr>
<tr>
<td>Unlike</td>
<td>Yes (monotony)</td>
<td>Yes (for stationary/walk)</td>
</tr>
<tr>
<td></td>
<td>Yes (confinement/space)</td>
<td>No (illusions/perc. contr.)</td>
</tr>
</tbody>
</table>