EXPERIENCE WITH THE SAFETY AND VENTILATION DESIGN IN OPERATION OF THE PLABUTSCHE TUNNEL

Waltl A. ¹ and Michelitsch F. ²

¹Styrian Government,
Department for Technical Equipment (FA 189
Landhausgasse 7, A-8010 Graz
²ASFINAG SGS, Kärntnerstraße, 8020 Graz

ABSTRACT:
For more than 17 years the Plabutsch tunnel was operated as single bore tunnel with bidirectional traffic. Two years ago the Plabutsch tunnel was opened as a twin tube tunnel with uni-directional traffic. Safety standards and the ventilation system were upgraded and new safety installations introduced. Since December 2004 both bores are in operation. This paper reports on the experience gained since that time with the operation of the safety systems and the ventilation of the tunnel.

Key words: road tunnel, operation, safety installation, ventilation

1. STATUS OF THE SAFETY AND VENTILATION DESIGN

The Plabutsch tunnel is still one of the longest tunnels in the world having two bores and unidirectional traffic. Since December 2004 the second bore is in operation. Hence it is possible to report on 2 years of continuous operation.

The safety standard and the ventilation design of the newly built 2nd tube as well as of the upgraded 1st tube of the Plabutsch tunnel was presented in detail at the 2nd international conference for safety and ventilation in Graz in 2004 (Waltl, 2004). The main items of these installations are:

- Reduction of the length of the single energy supply sections
- Cabling in E90 standard
- Traffic management with video image processing
- Emergency call system on bases of voice over IP
- Exhaust gas fans with 450kW and a temperature resistance of 400°C over 2 hours
- Improved lighting of the tunnel with lamp/body constructions fulfilling high temperature and tightness requirements

A main focus of the update of the ventilation system was put on the new ventilation concept in case of an incident. The ventilation control makes use of all 5 ventilation sections independently and allows a generation of air/smoke flows in longitudinal direction although the tunnel is equipped with a fully transversal ventilation system (Almbauer 2004, Waltl 2004)
1.1. Development in traffic volume

Traffic volume amounted already to over 30,000 vehicles per average working day. The development of the traffic volume is shown in Figure 1.

![Traffic Volume Plabutsch Tunnel 1987-2005](image)

Figure 1: Development of the traffic volume

In spite of higher traffic volume and an increased average speed (around approx. 40 km/h more than before), the number of accidents was reduced noticeably.

1.2. Energy consumption

The change in energy consumption of the tunnel was surprisingly. Due to the opening of the second bore the connection power requirement was more than doubled, from 5 MW to 10.5 MW. However, the improvements in tunnel lighting, ventilation control and utilisation of the self ventilation effect due to the piston effect, the overall energy consumption of the tunnel in operation did not increase at all.

Due to reduced pollution inside the tunnel (remarkably reduced amount of lost goods like gravel) and reduced re-suspension of dirt (due to reduced turbulence because no passing trucks like in counterflow) the in-tunnel air quality and the visibility improved remarkably. Figure 2 shows the changes in energy consumption since January 2004.
Figure 2: Energy consumption of the tunnel

1.3. Video image processing

High expectations were set into the video image processing, as this technology is ought to be the most up to date development in recognition of unexpected events in traffic monitoring. Unfortunately a high rate of false alarms occurred and a lot of updates of the process software were required to minimise the number of false alarms. At the moment different tests for event evaluation as well as a research project called VITUS are ongoing activities which take place in the Plabutsch tunnel.

It has to be noted, that in improvements in the operation surface are necessary. In addition, a pre-evaluation of recognised events in disturbances in traffic is required, before an alarm is triggered and sent to the dashboard in the operation centre and as a follow up action a measure like a tunnel closure is started.

Improvements in image processing are proposed for:

(a) congestions
(b) incident without fire
(c) smoke or incident with fire
(d) “ghost” driver (wrong way)
2. CONGESTIONS

To reduce the number of false alarms the information from the image processing has to be linked to information of traffic signals. I.e.: a red traffic signal shall not be interpreted automatically as “congestion”. The same is valid shortly after setting the signal to green where an accumulation of vehicles leads automatically to a “congestion” alarm. A link with parameters like acceleration or deceleration could reduce the frequency of false alarms.

![Figure 3: Detection of congestion](image)

Is a congestion message evaluated and recognised as true, the following actions should be started automatically:

- Automatic visualisation of the video pictures of the considered section in the control centre.
- Closure of the entrance
- Activation of a “speed reduction cone” (i.e., activation of different speed limits) in the approaching zone of the entrance portal.
- Information to the tunnel users.
- Increase of the illumination level in the concerned tunnel zone
- Increase of ventilation in the concerned tunnel zone
- Reduction of the “congestion recognition sensitivity” of the image processing system in order to avoid further triggering of alarms

3. TRAFFIC ACCIDENTS

![Figure 4: Image from a traffic accident](image)

Figure 4 shows an image taken from a detection of an accident and some lost goods (left hand side).

The detection of non-moving vehicles works relatively well. Problems occur when the road surface is wet. In such cases the reflections disturb the processing. New evaluation algorithm should yield to reductions of the false alarms.

The recognition of lost goods in the tunnel is not satisfactory.
In case of an evaluated alarm the following actions should be started automatically:

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4. FIRE AND/OR SMOKE IN THE TUNNEL

![Figure 5: Detection of a smoking vehicle](image)

The detection of smoke and smoking vehicles is sufficiently good. However, the location of the triggering of the alarm is in most cases not identical with the location of the incident (see Figure 5). Even for not moving smoking vehicles the “smoke” alarm is triggered in most cases by the camera in the second section next to the incident location. One reason could be in the “calibration” of the image processing software for the event of smoke.

If the detection is too sensitive a lot of false alarms will be the result, as e.g. re-suspended dust might have a similar appearance for the processing software. If once a fire alarm is triggered, cameras downstream the event shall not trigger new alarms, they might send an alert signal, but not more. Otherwise the fire location would virtually move downwards until it reaches the exit portal (in longitudinal ventilated tunnels).

The following actions should be started when a smoke/fire event is triggered:

- Increase of the illumination level up to the highest possible level.
- Pre activation of the exhaust fans in the concerned zone.
- Automatic visualisation of a moving smoke source by the cameras until the vehicle comes to a stand still.
- Closure of all tunnel entrances
- Setting of all traffic lights between entrance portal and incident location to red
The start of the automatic ventilation procedure for fire is coupled with the fixed fire detection system (cable) only and not with the CCTV. If the event is coupled with a stopped vehicle the CCTV brings the information to the operator and highlight automatically the correct ventilation procedure (response programme). The operator has than to confirm and start the programme manually (if not already started by the automatic system).

5. Wrong way driver

Ghost drivers are unfortunately not a very rare event in a tunnel (see Figure 6). They must be detected very quickly and with a high accuracy. All required system reactions have to be set automatically and without any time delay. Warnings for drivers in the correct way must be clear and unmistakably. The information can happen via tunnel radio or info boards. A stop of vehicles driving in the correct way might not be the best recommendation as a standing vehicle can not react anymore. The following actions are proposed:

- Warning via tunnel radio or/and info boards
- Switching illumination at highest level
- Automatic chasing of the wrong way driver by the cameras

Figure 6: Detection of a wrong way driver

6. OTHER REQUIREMENTS

All information systems must be able to switch automatically between uni- and bidirectional traffic. Useful would be the utilisation of statistical information to increase the detection limits. The consideration of sequences with increased traffic volume, daily change in traffic volume, special operation regimes like maintenance, etc. would be helpful. The following operation modes are an example:

- A shut off of the detection in certain sections is necessary e.g. at construction sites inside the tunnel (shall not yield to a full shut off of the system).
- Consideration of partial or short time counterflow is required.
- Short term reduction of the detection sensitivity after a traffic stop or at the region where a speed reduction is imposed.
6.1. Tunnel lighting

The strongly increased requirements enforced by the new RVS Standard have shown very positive effects.

The temperature requirement (250°C for one hour) and the proof of increased tightness are important features. The two fires recorded during the last two years showed that due to the E90 cabling and the increased temperature resistance of the lamps the effects of the accidents on the tunnel equipment could be kept low. In both cases it was possible to reopen the tunnel without any restriction already within a short time after removal of the damaged vehicles.

The usage of sodium vapour high pressure lamps showed positive effects although the illumination density was reduced.

Problems occurred with the illumination of the emergency niches. In these zones with higher illumination levels the metal vapour halogen lamps start to melt, due to too high temperatures (Figure 8). Currently a search for alternatives has been started.

6.2. Roadside marking with LEDs

The marking of both roadside is performed with LEDs. They have been proven to be very effective as orientation lights during fire events combined with dense smoke, as they are visible for a very long time (see Figure 9) and almost not affected by temperature. It is foreseen to upgrade the LEDs with active emergency exit signalling.

Not sufficiently is the usage of LEDs in context of pollution and operational safety. There is a strong request for an improvement of the durability in operation and an improved behaviour in a dirt environment.

Figure 7: Lamp after the fire event

Figure 8: Melted lamp during normal operation

Figure 9: Visibility of the LEDs in a smoke filled tunnel
7. EXPERIENCE WITH THE VENTILATION SYSTEM

The ventilation system and the incident ventilation philosophy have been presented in Almbauer (2004) and Waltl (2004). The main feature of the incident ventilation is the utilisation of all of the five ventilation sections to achieve the required ventilation result. A PID controller is employed to steer the system. The system has been developed and installed first time in the Plabutsch tunnel. It allows a built up of a controlled longitudinal air/smoke flow in this transversal ventilated tunnel. In 2005 this system had to prove its capability during a considerable fire accident.

7.1. Ventilation system

The Plabutsch tunnel is equipped with 5 ventilation sections in each tube. All of these sections are fully transversal. At the south portal a 400 m long section with longitudinal ventilation exists as due to environmental reasons no exhaust air shall be exchanged via this portal.

The 10 exhaust fans have a power of 450 kW each and are temperature resistant up to 400°C. They are speed controlled. The fresh air fans are speed controlled and have a variable pitch to support the starting procedure. Inside the tunnel two caverns exists. One has a vertical shaft of 100 m (south shaft), the other one 240 m (north shaft). Each cavern and vertical shaft supports 4 ventilation sections (2 per bore). The remaining 2 sections are supplied from the north portal station (seen Figure 10).

Hot smoke tests were performed to test and adjust the incident ventilation procedure. Some of the intensive tests were reported in Waltl (2004). The incident ventilation philosophy is based on the concept of generating over and underpressure in the various ventilation sections in order to steer the smoke to the proper exhaust gas damper (Almbauer 2004).

Figure 10: Sectional view of the tunnel

Figure 11: Cross section and damper
The hot smoke tests proved the functionality of the system already in 2004. One of the main features in the incident operation strategy is the exact detection of the fire location, as the exhaust dampers (12m²) are installed only every 106m. The opening of a wrong damper can have negative effects on the efficiency of the smoke extraction. In very unlucky cases it could even happen, that only fresh air would be extracted and the smoke would be kept inside the tunnel.

**7.2. Vehicle on fire**

In November 2005 the following incident happened. A vehicle started to burn and the ventilation had to react. The boundary conditions were very unpleasant as due to the uni-directional traffic a very high longitudinal air velocity occurred. **Figure 12** shows the location of the event.

![Figure 12: Sketch of the incident location](image)

The vehicle – a van with a caravan with a mass of more than 2 tons – was forced to stop shortly before the emergency niche A205. Most likely due to overheating the engine of the van caught fire. The driver tried to reach the tunnel exit with his burning vehicle. In the meantime other tunnel users had already called the fire department using their cellular phones. As they could not give the exact location of the burning vehicle it was not possible to find this vehicle immediately. The video system detected congestion and came up with the proper images and location information a few minutes later (17:44). From that time on the video system chased the smoking vehicle automatically. At that time the fire was still small. As soon as the vehicle stopped, the fire alarm was triggered and the incident ventilation procedure started.

The detection of the fire resulted in the opening of the damper next to the incident location (downstream the fire). The exhaust fan went up to full ventilation power in that section. Smoke extraction happened fully over this open damper.
Figure 13: Course of the air/smoke velocity over the time.

Figure 13 shows the development of the air velocity at the sensor responsible for ventilation control. At the beginning a very high longitudinal velocity of 7 m/s occurred. Although the system has never been tested at those high air velocities it was able to slow down the velocity within a very short time.

During the fire event the big connection doors between the two tubes were opened and closed. Such interferences as well as the manual opening of other dampers were compensated by the automatic PID controller without any problem.

Although the vehicle burned out totally (see Figure 14) and caused severe damage to the concrete surface (up to 7 cm in dept over an area of some square meters, see Figure 15), it was no problem to keep the tunnel from both sides of the fire fully free of smoke (except the zone between fire and open damper).

Due to the temperature requirements enforced for the cables, the equipment and the lights, there was no breakdown in any of the safety installations to be reported. The radio transmission cable had some damage, but transmission was possible without any restriction throughout the whole event.
8. CONCLUSION

After two years of operation of the new respectively upgraded Plabutsch tunnel a lot of experience was gained concerning operation of the tunnel. Although the second bore required an increase in electrical power by a factor of two, the energy consumption of the tunnel did not raise. This is due to improved efficiency of tunnel lighting as well as reduced ventilation power due to the utilisation of the self ventilation effect in uni-directional tunnels.

Many of the performed improvements in safety technology proved their usefulness and some showed that further improvements are required (e.g. video image processing, etc.). In any way, the concept of improving self rescue possibilities due to keeping the smoke away from possible escape routes showed to be very effective. Although the two fire events occurred during the last two years were not major fires, especially the event with the burning van showed the capabilities. The ventilation system was able to cope with unfavourable boundary conditions like high air speeds at event triggering, open cross passages, manual interference by tunnel operator, etc.

9. REFERENCES
