1. Introduction

The A2 motorway runs from Vienna down to the Austrian/Italian border. The highest section of this motorway is the ‘Mooskirchen-Pack’. The elevation ranges from 338 metres in the east and reaches 1,050 metres at the west portal of the Kalcherkogel tunnel. There are four tunnels along this section and a central control station at Unterwald. As a result of both the increasing traffic volume and the approaching end of useful life for the electrical and safety equipment, it became necessary to construct a second carriageway, and while doing so, replace all electrical systems.

Figure 1: A2 Motorway

Renovation and construction work on the new carriageway began on 6th May, 2003, and was completed on 28th June, 2007. Work on the new electrical and safety systems began on 1st December, 2004.

This presentation will focus on the new ideas used in the individual phases of the refurbishment process, and on the difficulties faced in overcoming conflicts between the new and old tunnel systems. Technical developments and test series will also be dealt with.
2. SUBJECT THEME

The ‘Pack’ chain of tunnels is part of one of the highest motorway routes in Austria. It was opened on 27th September, 1982, and included a section of approx. 20km in length with bi-directional traffic. By the time renovation work began, the initial traffic volume of 3,760 vehicles per day (1982) had risen to 18,300 vehicles per day. This fell somewhat during the construction phase, and reached a minimum of 17,100 vehicles per day by mid-2007.

![Figure 2: Development of traffic volume on A2 between Mooskirchen and Pack](image)

The costs of refurbishment and renovation were as follows:

<table>
<thead>
<tr>
<th>Tunnel Length</th>
<th>Costs</th>
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<tbody>
<tr>
<td>Assingberg tunnel</td>
<td>€ 2.4 million.</td>
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<tr>
<td>Herzogberg tunnel</td>
<td>€ 9.3 million.</td>
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<tr>
<td>Mitterberg tunnel</td>
<td>€ 6.0 million.</td>
</tr>
<tr>
<td>Kalcherkogel tunnel</td>
<td>€ 8.2 million.</td>
</tr>
<tr>
<td>Central Control Station / Unterwald</td>
<td>€ 3.9 million.</td>
</tr>
<tr>
<td>Adaptation of open carriageway along the 32km ‘Mooskirchen Pack’ section</td>
<td>€ 2.3 million.</td>
</tr>
</tbody>
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These figures cover the costs for all safety systems as well as the costs of adapting the energy supply systems.

The Pack tunnels are among the oldest in Austria and in part, they retained original structures in operation up to 2006. A further possible ‘highlight’ is the fact that the new tube of the Herzogberg tunnel was used as background scenery for the film ‘The Tunnel of Death’ (‘der Todestunnel’), which was shown in Germany, Switzerland and Austria.

![Figure 3: Film scene](image)
The logistical planning of Pack tunnel refurbishment had to be such that it allowed for maximum safety for the on-coming traffic diverted to the opposite tunnel tube, and to ensure sufficient progress such that unidirectional traffic flow was possible during holiday periods.

This resulted in the following phasing:

- Refurbishment of Herzogberg tunnel, southern tube,
- Renovation of Herzogberg tunnel, northern tube,
- Renovation of Mitterberg tunnel and Kalcherkogel tunnel, southern tube, followed by,
- Renovation of Mitterberg tunnel and Kalcherkogel tunnel, northern tube,
- Re-equipment of Assingberg tunnel, southern tube, and
- Renovation of control station in Unterwald, after which,
- Renovation of Assingberg tunnel, northern tube, and finally,
- Completion of the whole tunnel system.
Emergency power, illumination, ventilation, traffic management, and emergency call systems, as well as all other systems necessary for safety control were completely renewed. However, during the traffic re-assignment and transition period, one tube was operated using old safety systems, and one with new systems.

The new safety plan was designed to accommodate full back up systems, including all those needed for communication and monitoring networks in Unterwald. Full back up was also arranged for the control station and two workplaces were set up. At the same time, preparations were also made to ensure that all necessary data could be relayed to a further central control station in the Plabutsch tunnel.

![Unterwald Control Station](image)

**Figure 5:** Unterwald Control Station

The need to ensure that a 24 year old system remains available for parallel operation and that no serious disturbances are caused by necessary reconstruction work meant that a number of unusual measures had to be taken. One example here was the need to physically suspend the old, fully operational distributor units (see Figure 6). In the Mitterberg and Kalcherkogel tunnels, parallel cables in the second tube were used to supply the substations, until following the diversion of traffic, the old supply network was removed.

![Temporary suspension of distributor panels](image)

**Figure 6:**
Temporary suspension of distributor panels

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In connection with the safety system refurbishment in the Pack tunnels, one of the subcontractors, SWAREFLEX, developed a new intelligent signalling system which operates via the LED kerb indicators. Here, inductance coupling is used to supply the LEDs and the new system also means that single lighting units on both sides are independent and can be programmed individually. This makes it possible to achieve a variety of sequencing and flashing programmes even for on-coming traffic.

With regard to component quality, in particular cable quality, a special cable was developed which is easily capable of withstanding the relatively high temperatures found in asphalt road surfaces. Initial tests were also undertaken involving the installation of inductance coils and cables under the final road surface. These are particularly useful in periods requiring rapid re-assignment of lanes since centre line indicators can be activated for on-coming traffic. As damage of single inductance units has no impact on other units, activation of emergency exit indicators can still be carried out reliably in the event of fire. Based on research carried out at RWTH Aachen on the impact of light sequencing on traffic speed, initial trials were attempted in the Assingberg tunnel. Tests showed that a four unit light sequence might be beneficial. Apart from its impact on traffic speed, such an intelligent LED lighting system has the further advantage that it provides for active sequencing of exit indicators as well as the possibility to activate centre line indicators.

The ventilation system in the Pack tunnels is the first of its kind to use jet fans capable of withstanding temperatures up to 400°C. The fans were tested on a full scale model by the Munich University of Technology and easily survived such temperatures over 120mins.
The acceptance trials for the tunnel safety equipment involved numerous fire tests under a variety of circumstances. A great deal of valuable knowledge was thus gained with respect to the interplay of various factors, e.g. backlayering, tunnel gradient, the influence of connecting doors on ventilation control, smoke reversal etc. The new regulations for tunnel equipment (RVS 09.02.31,’Tunnelausrüstung, Belüftungsanlagen Grundlagen’) reflect the insights acquired.

In one test, an attempt was made to reverse the direction of smoke flow using the existing ventilation equipment. The attempt was not at all successful since by the time the automatic fire detection system reacted smoke had already travelled a few hundred metres upstream in the traffic direction. Reversing smoke flow then meant that the cooled smoke had to be fully extracted back along the tube resulting in a smoke-filled tunnel for a considerable length of time.

A second test was carried out in the (descending) tube of the Kalcherberg tunnel. Strong backlayering resulted in the pair of jet fans (situated ahead of the fire) filling the empty half of the tube with smoke and reducing visibility to zero. It is thus important to take tube gradient into account when considering the distance between fans and the location of the fire.

A further test revealed that an open door to a cross-connection had such a strong impact that the flow of smoke during longitudinal ventilation was no longer in the desired direction. Here, the inflow of fresh air results in a movement of smoke away from the fire and in the opposite direction of the traffic flow. Thus, as far as ventilation control in the case of fire is concerned, all openings to cross-connections ought to be considered as a potential source of risk and the control mechanisms need to be set accordingly.

All Pack tunnels have now been operating with the latest safety equipment and systems since 28th June, 2007. One-way traffic now operates throughout and the return of traffic flow to its pre-renovation days is well underway.