# RAPID INCIDENT DETECTION IN TUNNELS THROUGH ACOUSTIC MONITORING – OPERATING EXPERIENCES IN AUSTRIAN ROAD TUNNELS

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## ABSTRACT

AKUT is an innovative tunnel safety system based on the automatic detection of abnormal noises. Analyses on all live AKUT systems show that all relevant incidents in these tunnels were first detected by AKUT. The head start provided by AKUT in these incidents ranged from several seconds to over 11 minutes. Furthermore, false alarms were also explained. The analyses resulted in very low numbers of false alarms, which when paired with the high detection performance, led to extremely positive feedback from the operator. Aspects of microphone maintenance and cleaning will also be discussed using experience gained in a tunnel that has been operating for 8 years.

*Keywords: Acoustic tunnel monitoring, AKUT, microphone, operating experience, maintenance, detection rates*

## 1.    INTRODUCTION

The rapid detection of critical incidents in tunnels is essential for the triggering of emergency responses and the evacuation of people involved in accidents in the tunnel. Immediate reaction by the operators in the traffic management centre is not only important for the persons in the tunnel – rapid response is also important for the protection of the infrastructure.

In order to enable such rapid incident detection, JOANNEUM RESEARCH combined forces with ASFINAG (Austrian Motorway and Expressway Network Operator) to jointly develop a system for the acoustic monitoring of tunnels – AKUT. Comprehensive research and field tests were carried out between 2002 and 2009 leading to implementation of the first AKUT pilot system for ASFINAG in the Kirchdorf tunnel in 2010. Over the next 4 years, between 2010 and 2013, ASFINAG tested and evaluated the system in live operation. Parameters such as the detection rate, the head start over other safety systems and false alarm rates were of primary interest. However, other aspects underlying the decision to rollout the AKUT system in the ASFINAG network were the effort for maintenance, service and repair.

Due to the extremely positive evaluation results, in 2014 ASFINAG decided to rollout the system throughout Austria in all tunnels in hazard classes 3 and 4. The general agreement between ASFINAG and JOANNEUM RESEARCH provides for a total of 56 tunnel systems to be equipped with AKUT by 2029. When completed, approximately 3,500 microphones will have been installed in ASFINAG tunnels and the safety in Austrian tunnels will have been increased in 24/7 operation.

## 2.    ACOUSTIC TUNNEL MONITORING – HOW IT WORKS

The soundscape of noise occurring in tunnels is dominated by the sounds emanating from passing vehicles such as engine, rolling and air flow noise. Noise anomalies such as accidents, tyre squealing and even people shouting are detected by the microphones located in the tunnel. The distance between microphones is approximately 125 m, whereby a video camera and a microphone are installed at the same location.

Specially trained acoustic detectors recognise the abnormal sounds in real-time and allocate them to predefined noise classes. Accidents and other critical incidents in the tunnel are always accompanied by distinguishable sounds. These sounds occur at the instant in time of the incident  - not after a delay -  and can be detected immediately.

The huge advantage of acoustic detection is that AKUT can react **directly** to the critical incident (e.g. accident noise after a collision). This means that AKUT can trigger an alarm in the traffic management centre just 0.7 seconds after the incident. Other safety systems usually recognise the consequences of an accident **indirectly** (e.g. slow drivers, queues, etc.) and hence require a longer amount of time to trigger an alarm.

After rapid detection by AKUT, the operator can immediately capture the situation by activating the corresponding camera and trigger the appropriate actions. This saves valuable time and provides the parties involved in the accident and the following vehicles with the maximum of emergency response and accident prevention measures.

Currently, the following sound classes are detected:

- Accident / tyre burst
- Tyre squeal
- Door slam
- Honking
- Voices/shouting (VoiceScan)


## 3.    HARDWARE STRUCTURE

The first elements in the signal chain are the microphones mounted in boxes located in the tunnel. The microphones are encased in a special membrane that protects them from water and fine dust ingression. The membrane does not require any additional cleaning. The microphones are cleaned as part of the normal, periodic tunnel washing activity. If the protective membrane needs replacing, this can be done within a few seconds.

There are three variations for the hardware structure layout. Depending on the available infrastructure in the tunnel, one of the following variants can be selected:

Variant 1: Microphone and Smartcam

In this variation, the microphone is directly connected to the Smartcam. The Smartcam digitalises the audio signal and generates an IP-data stream that is transmitted over a network (optical or electrical).
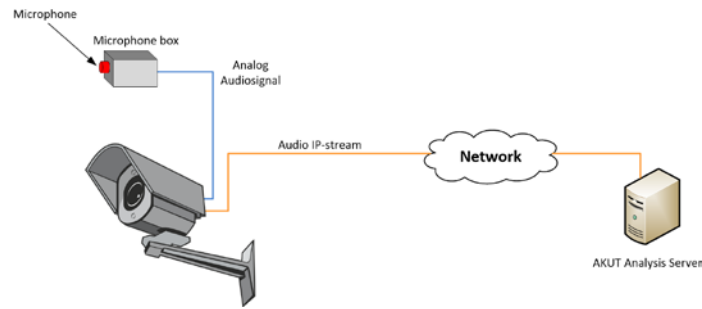
**Figure 1:** System structure when using Smartcams

Variant 2: Separate Audio Network

The audio signals in this variation are transmitted to the analysis server via a separate audio network. This variation is used if an existing video system is to be refurbished with AKUT.
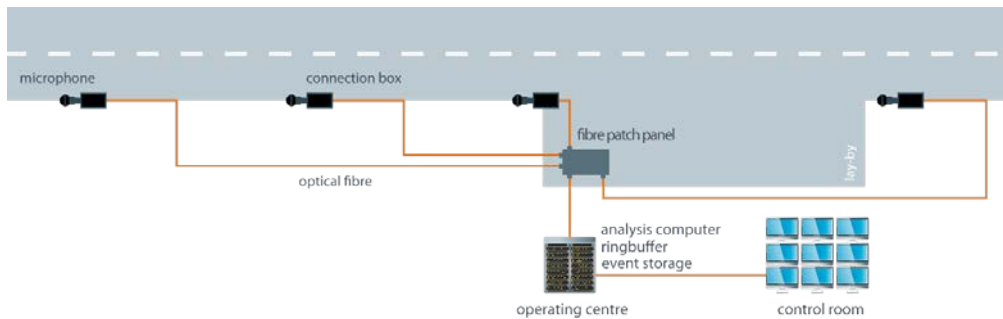


**Figure 2:** System structure when using an audio network

Variant 3: Combined Audio and Video Network

If the audio and video networks are combined in a similar fashion to variant 1, then the costs for the data transmission devices can be saved. The audio and video signals from a location are transmitted together on a single cable (optical or electrical).
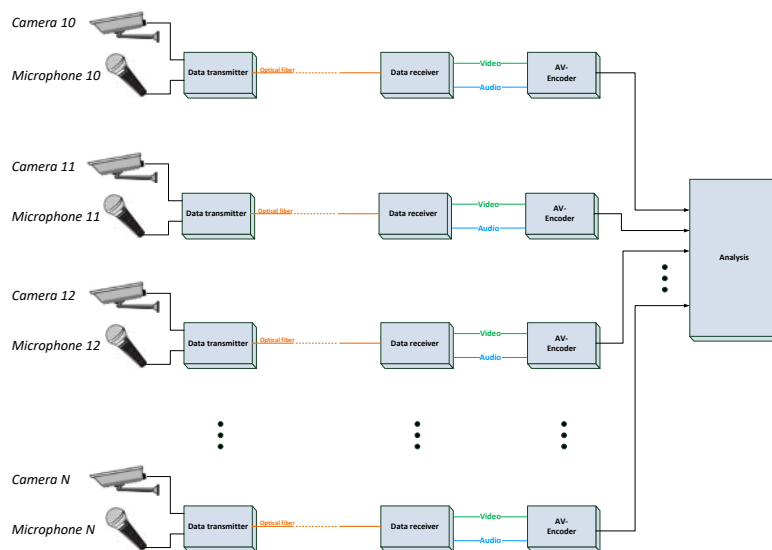


**Figure 3:** System structure when using a combined audio and video network

## 4. AKUT INSTALLATIONS

As of March 2018, AKUT systems have been installed in 22 tunnels run by ASFINAG in Austria and in the Southwick tunnel in Great Britain. Currently, 1150 microphones run in 24/7 operation and trigger alarms for abnormal noises.

In Austria, as of March 2018, 3 AKUT systems are under construction, 4 systems are in the planning stage, and 27 tunnel systems are in ASFINAG's construction programme up to 2029. When completed, ASFINAG tunnels will contain approximately 3,500 microphones.

In parallel to the activities in Austria and Great Britain, work is in progress on the rollout of AKUT systems in other countries.

## 5. OPERATIONAL EXPERIENCE

### 5.1. Evaluation of current systems using the ASFINAG incident database

The first AKUT systems for ASFINAG went online in the middle of 2016. Over 1.5 years of operational data with these first AKUT systems are now available. Specifically, the following systems were analysed:

**Table 1**: Overview of tunnels used for the incident analysis

| Tunnel | Length in m | Number of bores | Number of microphones | Average Daily Traffic Volume |
|---|---|---|---|---|
| **Bosruck, A9** | 5,505 | 2 | 122 | 17,470 |
| **Ehrentalerberg, A2** | 3,345 | 2 | 75 | 30,623 |
| **Falkenberg, A2** | 1,090 | 2 | 26 | 30,623 |
| **Lendorf, A2** | 800 | 2 | 20 | 30,623 |
| **Trettnig, A2** | 450 | 2 | 12 | 30,623 |
| **Götschka, S10** | 4,435 | 2 | 86 | 37,298 |
| **Neumarkt, S10** | 1,970 | 2 | 38 | 37,298 |
| **Pernau, S10** | 245 | 2 | 4 | 37,298 |
| **Lest, S10** | 545 | 2 | 12 | 37,298 |
| **∑ 9 Tunnel** | **∑ 36.77 km Bore length** | | **∑ 395** | |

The ASFINAG incident database, where all events are documented in detail, was used as the basis for the following analyses. As a first step, all incidents were evaluated that have been documented in the incident database since July 2016. Each incident was analysed in detail using the alarm messages and alarm lists from the traffic control system. The evaluation primarily followed the order in which the alarm messages occurred after an incident.

In the period from July 2016 to February 2018, a total of 28 incidents were documented in the incident database for the specified systems. Of these 28 incidents, nine were not included in the analysis. From the nine that were not evaluated, six occurred outside the tunnel and the entrance portal or gallery area (where no microphones are installed), the data set for one incident was not complete. One incident was a vehicle underbody fire, and in one event, the vehicle merely rolled onto the traffic lane without causing any further damage. This means that 19 incidents were relevant for further evaluation. **Table 2** shows the classification of these 19 incidents.

**Table 2**: Classification of the relevant incidents

| Incident type | |
|---|---|
| Rear-end collision | 5 |
| Collision of 2 vehicles | 4 |
| Collision of a vehicle with the infrastructure | 10 |
| **Total** | **19** |

The results of the analysis show that all 19 incidents were detected quickest by AKUT, without exception. This means that the operators first received an alarm message from AKUT for every incident, whereby the cameras were then activated and the operator could observe what was happening in the tunnel after approximately 0.7 seconds.

**Figure 4** shows the head start AKUT provides via its alarms. It can be seen that for 58% of the incidents, the time advantage provided by AKUT was up to one minute, and for 42 % of the incidents, the time advantage was greater than one minute. The largest head start compared with other safety systems was 11 minutes and 46 seconds. Two incidents were exclusively alerted by AKUT.
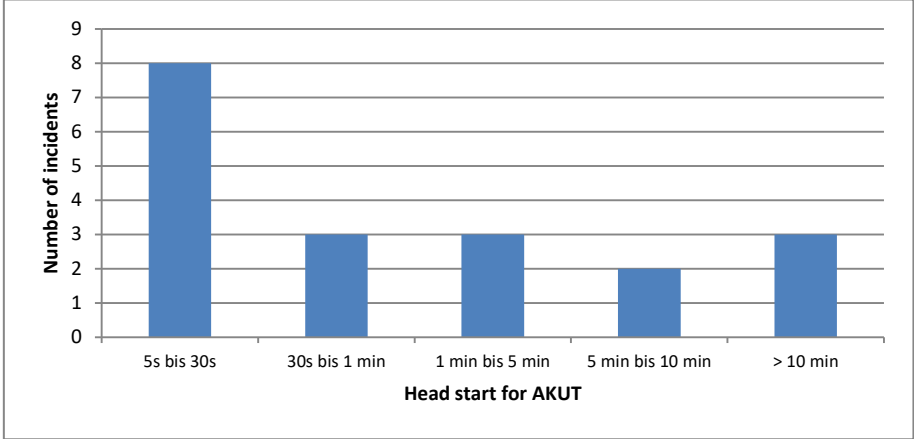


**Figure 4:** Head start provided by AKUT compared to other tunnel safety systems

In this context, it is also interesting to note which safety systems reported incidents to the traffic control system in second place after AKUT. **Table 2** shows the distribution of the alarms provided by other safety systems.
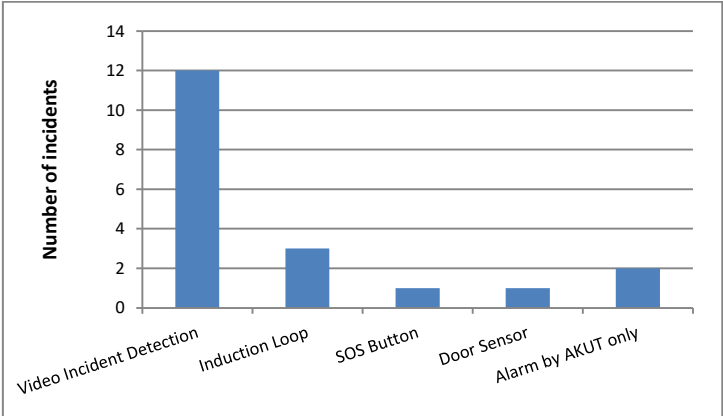


**Figure 5:** Distribution of alarm reports by other safety systems that reported alarms in second place after AKUT

## 5.2. Detection of loose manhole covers

Water is removed from the tunnel via tunnel drains and corresponding shafts that are closed with manhole covers. The manhole covers are bolted down with several bolts to prevent them from jumping out, for example by the suction effect caused by a passing truck.

During the operation of AKUT systems, operators in the traffic control centres noticed that the detectors also reacted to loose manhole covers. Since traversing loose manhole covers causes a noise impulse which sounds similar to the slamming of a door, the noise of a loose manhole cover was largely detected as a "door slam".

Several events were documented, where AKUT detected loose manhole covers very early on and triggered an alarm. After the alarm had been verified by the operator, the offending tunnel bore was immediately closed and repairs effected.

AKUT was thus able to successfully prevent serious traffic accidents caused by "open manholes". The detection of loose manhole covers was not considered in the product development phase. In the meantime however, the long-term operation of AKUT has shown that the detection of loose manhole covers is an essential contribution to the prevention of critical incidents in tunnels.

## 5.3. False alarms

The main task of a detection system in the safety domain is of course the detection of real incidents. On the other hand, the number of false alarms is an enormously important criterion for the practical operation of a system. If too many false alarms occur, the system will not be taken seriously by the operators and at some in the near future, it will be switched off. This section therefore focusses on the typical number of false alarms triggered by the AKUT system in live operation.

To do this, evaluations were carried out for incidents from 2016 through 2018 for different tunnels. Tunnels in eastern and western Austria were analyzed, along with short and long tunnels.

**Evaluation of the Bosruck Tunnel September 2016**

The evaluation in **Table 3** shows that the Bosruck Tunnel had 29 false alarms in the month of September 2016. This corresponds to 0.96 false alarms per 24 hrs for the complete tunnel system with a length of 11,010 m. If false alarms were to be nominalized to kilometer bore length, this would correspond to 0.0877 false alarms per 24 hrs per kilometer.

**Table 3**: Evaluation of false alarms in the Bosruck Tunnel, September 2016

|  | Sound class | Number of false alarms per month | False alarms per km bore length and per 24 hrs |
|---|---|---|---|
| Tunnel analyzed: Bosruck | Accident / tyre burst | 1 | 0.003 |
| Bore length: 11,010 m | Tyre squeal | 12 | 0.0363 |
| Number of microphones: 122 | Door slam | 16 | 0.0484 |
|  | Honking | 0 | 0 |
|  | TOTAL | **29** | **0.0877** |

Three further evaluations follow. They can be explained analog to the evaluations shown above.

## Evaluation tunnel sequence S10 September 2016

**Table 4**: Evaluation false alarms tunnel sequence S10, September 2016

| | Sound class | Number of false alarms per month | False alarms per km bore length and per 24 hrs |
|---|---|---|---|
| Tunnel analyzed: Götschka, Neumarkt, Pernau, Lest | Accident / tyre burst | 8 | 0.018 |
| Bore length: 14,390 m | Tyre squeal | 21 | 0.048 |
| Number of microphones: 140 | Door slam | 65 | 0.15 |
| | Honking | 0 | 0 |
| | TOTAL | 94 | **0.216** |

## Evaluation Ehrentalerberg tunnel, March 2017

**Table 5**: Evaluation false alarms Ehrentalerberg tunnel, March 2017

| | Sound class | Number of false alarms per month | False alarms per km bore length and per 24 hrs |
|---|---|---|---|
| Tunnel analyzed: Ehrentalerberg | Accident / tyre burst | 6 | 0.0298 |
| Bore length: 6,690 m | Tyre squeal | 6 | 0.0298 |
| Number of microphones: 75 | Door slam | 20 | 0.0996 |
| | Honking | 1 | 0.0049 |
| | TOTAL | 33 | **0.164** |

## Evaluation Flirsch tunnel January 2018

**Table 6**: Evaluation false alarms Flirsch tunnel, January 2018

| | Sound class | Number of false alarms per month | False alarms per km bore length and per 24 hrs |
|---|---|---|---|
| Tunnel analyzed: Flirsch | Accident / tyre burst | 0 | 0 |
| Bore length: 2,252 m | Tyre squeal | 0 | 0 |
| Number of microphones: 19 | Door slam | 17 | 0.243 |
| | Honking | 0 | 0 |
| | TOTAL | 17 | **0.243** |

The analysis of the false alarm rate shows that, in general, the number of false alarms on AKUT systems is very low. Coupled with an excellent detection performance (see section 5.1), this is also the main reason why AKUT is well accepted by operators in traffic control centres and is regarded as valuable support for daily operation.

### 5.4. Cleaning and maintenance

The maintenance of safety equipment in tunnels is an essential topic for tunnel operators. The frequency of required maintenance actions, fault susceptibility and the associated availability of a system are of primary concern for the operator after commissioning of a system is complete.

The AKUT system in the Kirchdorf tunnel went live in 2010. The AKUT system in Kirchdorf tunnel consists of 49 microphones and the total bore length is 5,614 m. The Average Daily Traffic Volume is 19,330.

Experience over the past 8 years of operating the tunnel can be summarized as follows:

- No form of maintenance of repair work has been required for the microphones or the signal transmission devices since commissioning in 2010
- No form of cleaning work has been carried out on the microphones or the protective membrane since 2010
- Not one microphone has failed since 2010
- In 8 years of operation, the server hard disks only had to be replaced twice as they were defective

However, the Kirchdorf tunnel analysis server will be completely replaced by a new server, since several hard drives are defective and the exchange of disk drives after 9 years is no longer economically viable.

In summary, it can be said that the maintenance costs for AKUT systems facing a tunnel operator are very low and do not represent significant extra effort.

## 6. SUMMARY AND CONCLUSIONS

The acoustic tunnel monitoring system – AKUT is an innovative safety system for tunnels that is based on the automatic detection of abnormal sounds (accident, tyre squealing, etc.). Thanks to the large installed base in Austrian tunnels, it has been possible to gather comprehensive operational data since 2016 and use it for analysis and explanations. The detected incidents were analyzed. The foundation was provided by the ASFINAG incident database. The evaluations show that 19 relevant incidents have occurred since mid-2016. All 19 incidents were detected by AKUT first, without exception. The head start provided by AKUT ranged from 5 s to 11 minutes 46 s. Two incidents were only detected by AKUT. The false alarms on different systems were also evaluated. The results show approximately 0.08 to 0.24 false alarms per 24 hrs and per km tunnel bore length. Due to the very low false alarm rate and the excellent incident detection performance, AKUT is well accepted by operators. Experience regarding maintenance and cleaning is available from the pilot system, which has been in operation since 2010. From 2010 to 2018, no periodic maintenance or repair work was carried out on the system components (e.g. microphone and data transmission devices). Neither was cleaning required and no microphone was replaced, since no microphone has failed since 2010. All in all, AKUT has provided excellent operational service in Austrian tunnels and during this period, AKUT has made an important contribution to the increase in safety in ASFINAG's tunnels.