Upgrading the Karavanken Tunnel according to the EU-Directive 2004/54/EC

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Abstract

The Karavanken tunnel forms an important link between Slovenia and Austria. The almost 8 km long tunnel is operated with bi-directional traffic and does not have dedicated escape routes. Moreover, the ventilation in case of fire is not up to date.

The EU Directive 2004/54/EC [1] specifies the minimum requirements for tunnels in the trans-European road network. In case of existing tunnels, the requirements are in some areas less stringent than for new ones.

The paper presents a case study that was undertaken in order to reach the required level of safety according to [1] at relatively low costs. It is shown that with simple but novel adaptations of the ventilation system, a sizeable increase in the overall level of safety can be achieved.

Keywords

Karavanken tunnel, EU-directive 2004/54/EC, tunnel ventilation, tunnel safety, novel ventilation system, moderate cost, ITA, PIARC, RVS

1 INTRODUCTION

The Karavanken tunnel imposes an important liaison on highway A11 between Slovenia and Austria and is hence a part of the trans-European road network. The about 8 km long tunnel is operated with bi-directional traffic. Since the inauguration in 1994, national and international safety requirements have been increased considerably. Tunnels in the trans-European road network shall adhere to the minimum safety requirements set by the EU-directive 2004/54/EC [1]. For existing tunnels, the requirements are somewhat lower than for new ones. Some national standards demand even higher levels of safety and are often more specific than outlined in [1].

The tunnel ventilation is an important element of the tunnel safety systems in particular for the Karavanken tunnel, as the only escape routes are the tunnel portals. According to [1], emergency exits every 500 m should be present. However, in existing tunnels, this has to be evaluated in a cost and feasibility study for each individual case. On the other hand, transverse ventilation is mandatory for tunnels that have a control centre.

Consequently, this study is devoted to develop a feasible ventilation concept at minimum cost that would adhere to modern standards as stated in [1]. The objective is to have localised smoke extraction using remote-controlled dampers. In this way, the smoke can be extracted close to the fire and therefore reduce the smoke spread to a short zone. Consequently, the escape routes are safe enabling the tunnel users to escape. The study is at conceptual level and further investigations are necessary in order to refine details of the proposal.

2 EXISTING TUNNEL

2.1 Geometry

The geometry of the tunnel, as shown in Figure 2.1 and Figure 2.2, was extracted from [2].

- –Length of tunnel: 7'864 m
- –Length of fresh-air and exhaust-air ducts on Austrian side: 3'332 m
- –Length of fresh-air and exhaust-air ducts on Slovenian side: 3'332 m
- –Length of tunnel in middle without ducts: 1'200 m
- –Cross section of fresh-air and-exhaust air ducts 9 m^2
- –North Portal:
  - o Kilometre 16,069 km / 0 km
  - o Height above sea level 655,30 m
- –Summit:
  - o Kilometre 19,949 km / 3'880 m
  - o Height above sea level 673,60 m
- –South portal:
  - o Kilometre 3,450 km / 7'864 m
  - o Height 620,68 m
- –Longitudinal slopes from north to south:
  - o +0,50 % over 3'880 m
  - o -1,35 % over 3'984 m
- –Cross section of traffic space 48,80 m^2

2.2 Escape routes

Only the tunnel portals are escape routes.

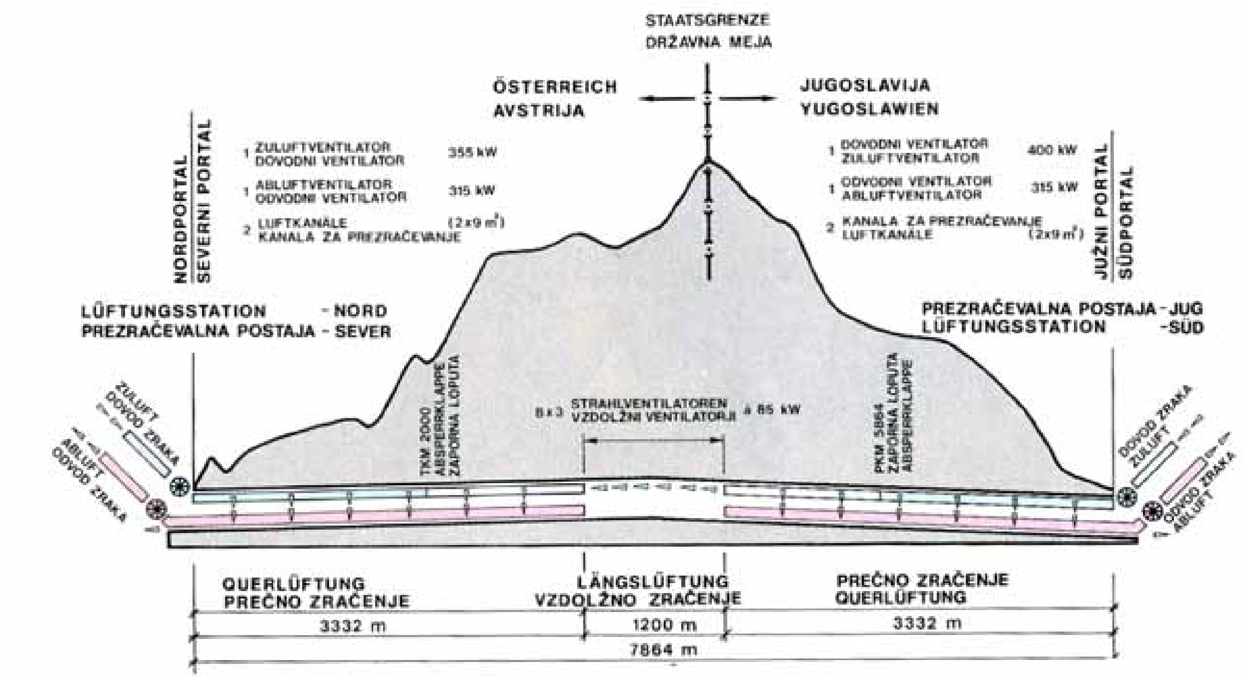

Figure 2.1 Longitudinal profile showing ventilation system. No ducts for smoke extraction over 1'200 m in the middle of the tunnel

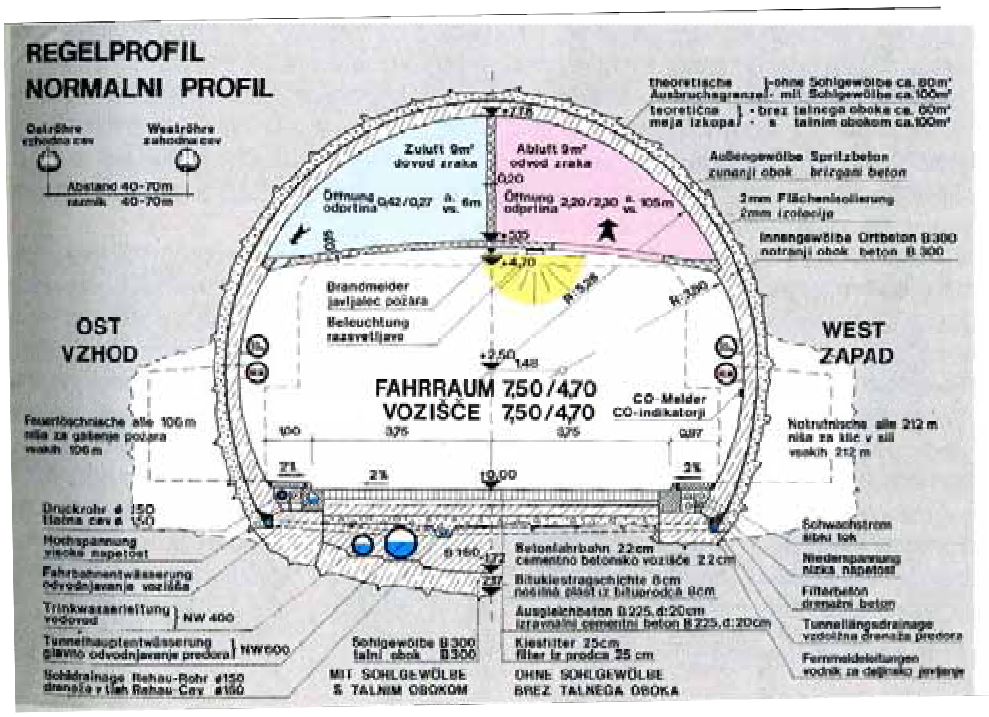

Figure 2.2 Cross section showing the two ducts for fresh air and exhaust air

2.3 Traffic

The average daily traffic is estimated to 14’000 with about 15% heavy-goods vehicles. From a traffic capacity point of view, the tunnel is not operating at its limits and a second tube is therefore not called for. This is also supported by [1] that demands a second tube when the average daily traffic exceeds 10’000 vehicles per lane. With two tubes, the tunnel could be equipped with cross passages for escape routes and would operate with unidirectional traffic, which inherently increases the level of safety.

2.4 Current ventilation system

The Karavanken tunnel is equipped with semi-transverse/transverse ventilation as well as longitudinal ventilation. The jet fans used for the longitudinal ventilation system are installed at the central 1’200 m of the tunnel, see Figure 2.1. Consequently, in this section, no smoke extraction is possible.

Fresh air is injected over the openings in the false ceiling. About 2 km from the portals, a damper can block off the ends of the fresh-air ducts. In this case, no fresh air is injected over about 5 km of the middle part of the tunnel, see Figure 2.1. Exhaust air is extracted through dampers at distances of 105 m. The openings are 2.20x2.30 m^2, see Figure 2.2.

During normal operation, either one duct is used in order to have semi-transverse ventilation or both ducts resulting in transverse ventilation. In case of fire, only the exhaust duct is used in order to extract the smoke, see Figure 2.3. Moreover, the jet fans could be used for longitudinal ventilation in case of fire and during normal operation.

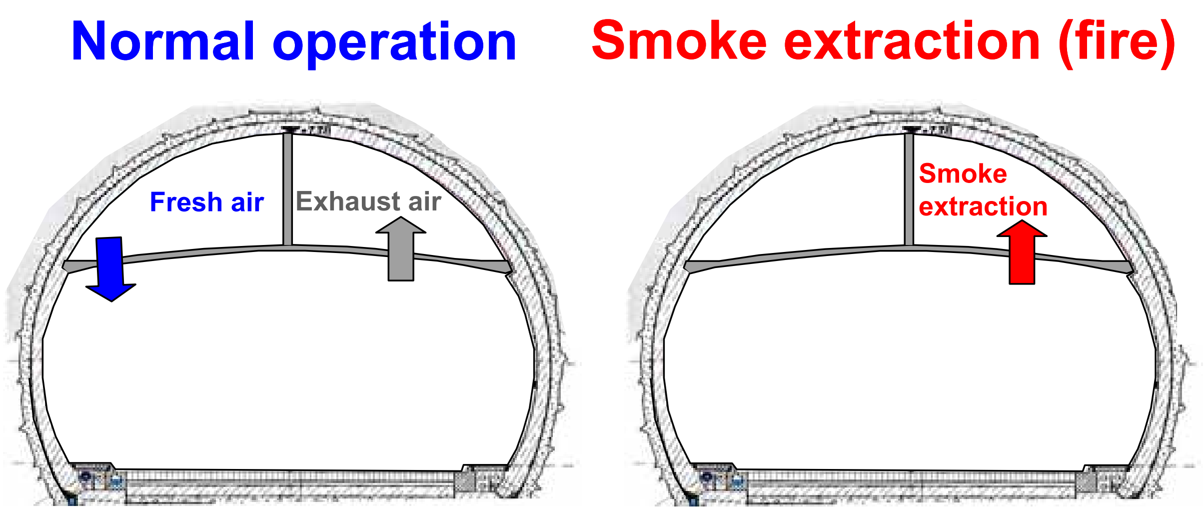

Figure 2.3 Left: ventilation in normal operation as semi-transverse (only fresh air) or transverse ventilation. Right: Smoke extraction in case of fire.

3 CURRENT REQUIREMENTS

3.1 Safety installations: escape routes and tunnel ventilation

The safety level should reach the demands according to national requirements i.e. from Slovenia and Austria. Moreover, the EU-directive 2004/54/EC [1] shall be satisfied. Presently, it can be assumed that these minimum requirements specified for the trans-European road network eventually will be applied world wide.

The Austrian design guideline RVS 9.261/09.02.31 [3] and the EU-directive [1] demand that the Karavanken tunnel is equipped with a smoke extraction. The minimum smoke-extraction rate is 120 m3/s, which are extracted over a maximum length of 150 m. The distance between the remote-controlled dampers used for the smoke extraction should not exceed 110 m. Further valuable information about the state of the art considering tunnel fires is stated in the PIARC report 1999 [4].

For the Karavanken tunnel, the feasibility and benefit of the construction of escape routes has to be examined [1]. However, there is no explicit demand to construct such escape routes as long as other safety measure e.g. tunnel ventilation ensures an adequate level of safety for the tunnel users. It also appears that the Austrian design guide does not implicitly demand the construction of escape routes [3].

The heat-release rate in case of fire for the dimensioning of the ventilation system is 30 MW [3]. However, if the percentage of heavy-goods vehicles exceeds 15%, 50 MW can be envisaged. The smoke extraction system has to function 120 min at temperatures of up to 400°C. Furthermore over a period of 60 min, the mechanical installations may not be destructed even at temperatures of 750°C.

3.2 Ventilation during normal operation

The computation of the fresh-air demand is to be conducted according to the newest version of the Austrian guide line RVS 9.262 (09.02.32) [4] and the PIARC 2004 [6] recommendation.

4 NOVEL VENTILATION CONCEPT TO REACH REQUIRED LEVEL OF SAFETY

4.1 Short comings with existing ventilation system

The smoke management in case of fire does not meet current standards, see Figure 4.1. Firstly, no smoke extraction is available over the middle 1'200 m of the tunnel. Secondly, the smoke-extraction rate is only 65 m^3/s per km. Compared with the required 120 m^3/s over 150 m, the extraction capacity is less than 10% of the required one.

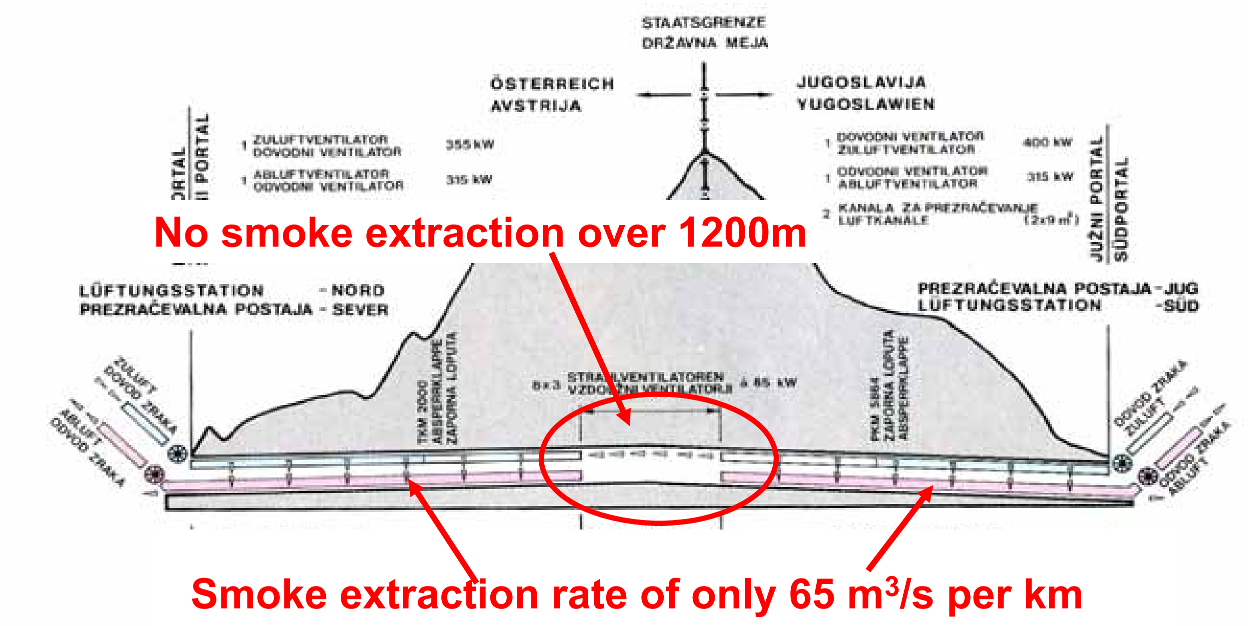

Figure 4.1 Short comings of existing ventilation system

4.2 New ventilation concept

The prime idea behind the proposed new ventilation concept is to connect the fresh-air and the exhaust-air ducts across the middle 1’200 m of the tunnel, see Figure 4.2. Consequently, smoke extraction is enabled from both portal-ventilation stations concurrently. This reduces the power consumption and implicitly ensures a certain degree of redundancy. Dampers are installed at 100 m intervals as for the current exhaust duct.

The fresh-air ducts are also connected. The existing fresh-air openings are closed and replaced by dampers at intervals of, say, 50 m. Having 180° variable-pitch fans, the flow can be reversed without changing the direction of rotation of the fans. Therefore, the flow can relatively quickly be reversed from fresh-air supply to smoke extraction.

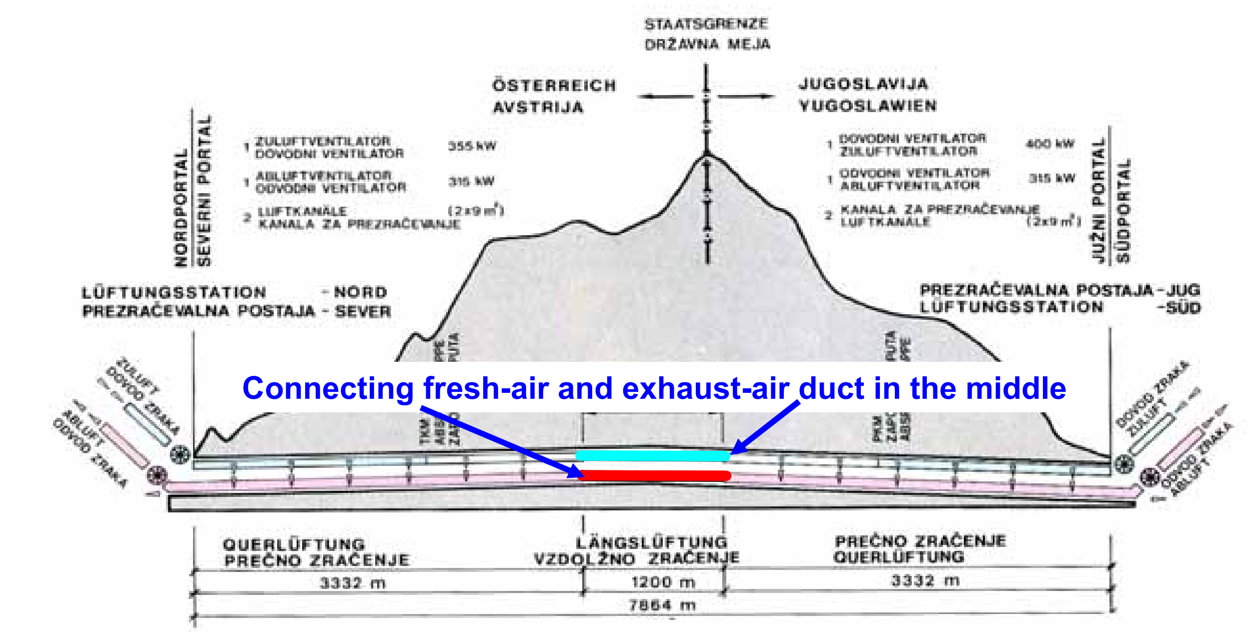

Figure 4.2 Connection of ducts enabling ventilation from both portals

During normal operation, the dampers are only slightly opened achieving a uniform fresh-air respectively exhaust-air distribution over the length of the tunnel, as it was done e.g. in the Vue-des-Alpes tunnel (Neuchâtel, Switzerland). In case of fire, 2 dampers in the exhaust-air duct and 4 dampers in the reversible air duct are opened and the extent of the extraction zone is 150 m. Smoke ist extracted at full capacity, see Figure 4.3.

With this concept, a minimum of 200 m^3/s can be extracted without increasing the currently installed power consumption of the axial fans. In this case due to leakage of the ducts, the four axial fans would extract in total 320 m^3/s. Is more power at disposition, the smoke extracted at the location of the fire could be increased to at least 280 m^3/s. These proposed extraction rates of 200 m^3/s and 280 m^3/s are to be compared with the minimal one of 120 m^3/s according to [3].

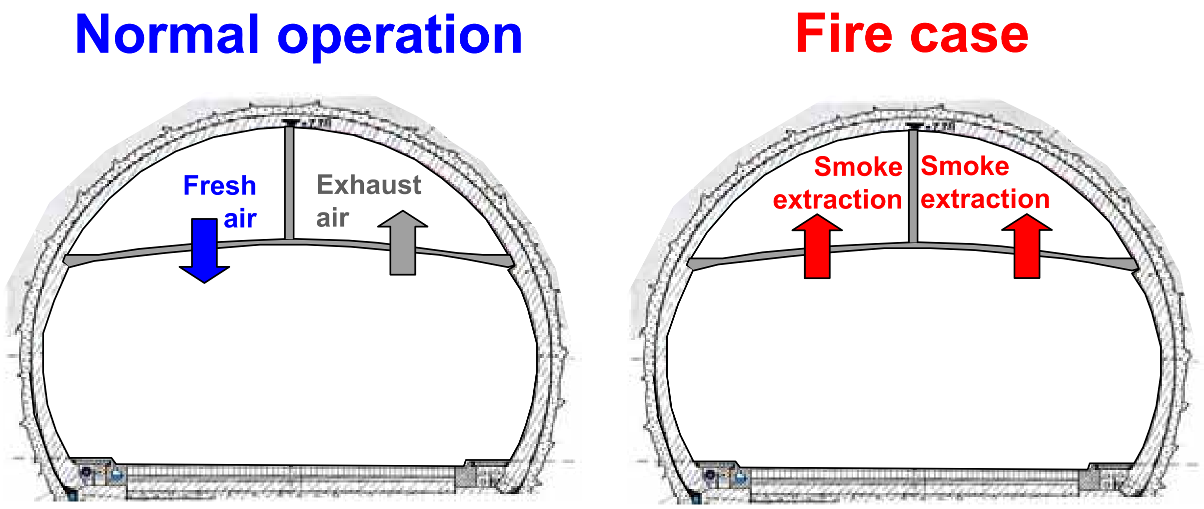

Figure 4.3 Left: normal operation that can also be operated only using only one duct. Right: smoke extraction using both ducts

In order to obtain an efficient smoke extraction, air should flow towards the extraction zone from both sides at about equal speed. In the centre of the extraction zone, the flow speed is insignificant i.e. close to zero. Consequently, ventilation equipment is needed that can influence the longitudinal flow during the smoke extraction. Due to the relatively small longitudinal slope of the tunnel, primarily the meteorological forces need to be outbalanced. Several options are at disposition:

- –Installation of jet fans in niches imbedded in the new 1’200 m long false ceiling that connects the ducts
- –Installation of unidirectional jet fans or Saccardo fans at the portals that blow into the tunnel
- –Use of air curtains
- –If lower extraction rates that assumed so far are permissible, no reversible flow ducts are needed. Consequently, the tunnel would have one dedicated fresh-air duct and another dedicated duct for smoke and exhaust air. In this case, the fresh-air duct can be used to influence the longitudinal flow in the tunnel.

It has to be examined whether or not existing fans and dampers can be refurbished to meet current requirements in particular with respect to temperature resistance. Also the fan buildings need examining in particular in case of the reversible flow duct.

4.3 Aspects of tunnel-ventilation control

The operation of the tunnel is to be considered during the detailed design of the ventilation system in order to ensure that the design is adequate. For this purpose, the tunnel including duct and ventilation equipment with sensors of air quality and flow velocities in the various sections is to be modelled e.g. using an adaptation of the program IDA RTV [7]. The control routines are part of the modelling that assumes time-varying traffic.

It is proposed to use this computer model as a tunnel simulator during the testing of the control system. In this way, numerous inevitable flaws and possible short comings can be resolved during the factory tests of the SCADA system prior to installation on site. This was successfully conducted for the Cross City Tunnel (Sydney) [8] with the benefit that the commissioning time was shortened tremendously and the quality much higher. As a matter of fact, no adaptation of the ventilation-control system was required after installation on site although the numerous project-specific requirements were difficult to meet.

Several systems are used in order to detect fires and it should also be envisaged to engage the opacity sensors for smoke detection by using novel data analysis [9].

In case of smoke extraction and longitudinal smoke management, it is paramount to control the longitudinal velocity correctly in order to optimise the extraction efficiency [10].

A distinct a rigid hierarchy, which requires careful engineering, shall ensure that the automatic operational procedures cater for adequate air conditions at all times [11]. The transitions between various scenarios e.g. between normal operation and fire mode has to be considered also for the equipment-redundancy situations.

5 COST ESTIMATE

At this conceptual level, the cost estimate is bound to be rather coarse. The installation of the false ceiling in order to connect the ducts is estimated to EUR 3 million. This is to be compared with other civil measures. A parallel escape tunnel is estimated to cost at least EUR 60 million. A second traffic tube would amount to more than EUR 340 million. Consequently, the proposed concept costs between 1% and 5% of alternative solutions to enhance the level of safety.

Irrespectively of solution, some renewal of the ventilation equipment is probably needed which is estimated to cost from EUR 7 to 10 million. A complete renewal of the electromechanical equipment would require investments in the order of EUR 40 million.

6 CONCLUSION

A novel ventilation concept that would fulfils the current safety standards can be realised at relatively moderate efforts.

Other measures such as a parallel tube or an escape tube would require much higher investments.

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