REPORT

The effects of the limitations of the FM rebroadcast system in Dublin Port Tunnel on the safety of tunnel users.

For

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1. **Dublin Port Tunnel Overview**

Dublin Port Tunnel is 4.5 km in length and is orientated in a North/South alignment connecting Dublin Port to the M50 ring road (see Figure 1). It is a twin bore tunnel comprising two tunnels running alongside each other providing separate unidirectional northbound and southbound traffic routes. The bore width is 11.8 metres and accommodates two traffic lanes of 3.65 metres each (see Figure 2). The bore height is 4.9 metres allowing passage of Heavy Goods Vehicles of up to 4.6m metres high. There are 15 pedestrian crossing points between the bores located at 250m intervals and 4 vehicle crossover points located 1km apart. Passage through these crossover points is controlled by doors and gates which are normally closed. There are emergency niches in the left wall of the tunnel at 250m intervals.

The tunnel was opened in December of 2006 and although initially intended as a dedicated route for heavy goods vehicles (vehicles over 3.5 tonnes and coaches over 25 seats), approximately 60% of the current 15,000 average daily traffic flow consists of cars and other vehicles.

The operation and maintenance (O&M) of the tunnel has been performed for the National Roads Authority by Egis Road and Tunnel Operation Ireland since 2006. The tunnel control room located at the south entrance is the management centre for the O&M of the tunnel. The control room contains the SCADA system (supervisory control and data acquisition) which co-ordinates data from remote units - CCTV cameras, fire and chemical sensors, traffic signals and stop signs, variable message signs, the PA system and the FM rebroadcast break-in facility - to provide feedback and control channels necessary to ensure the safe and smooth running of the tunnel. Traffic control is implemented by variable message signs, lane control signals, conventional traffic signals, variable speed limit signs and barriers at the tunnel portal (see Figures 3 & 4).

2. **In-Tunnel Communications.**

There are fixed line emergency telephones in the niches in the left wall of the tunnel which allow communication to the control room.

A public address system is provided within the tunnel and at the portals which allows the tunnel operators to broadcast messages to tunnel users.

Wireless infrastructure supports separate radio systems for emergency services, tunnel operations staff and the rebroadcast of public radio stations. Due to the propagation characteristics of radio waves, FM radio reception is not available inside tunnels without provision being made to rebroadcast the signal along the
length of the tunnel. In Dublin Port Tunnel, the FM radio signal is rebroadcast by means of a radiating cable (also known as a leaky feeder) which runs along the length of the tunnel (see Figures 5 & 6). The signal for emergency services and tunnel operation staff radio is provided in the same way. The leaky feeder is a coaxial cable which has precisely dimensioned slots cut in the outer conductor to allow a controlled amount of radio signal to leak out and be transmitted into the surrounding area. This is a conventional and well established means of providing radio and wireless communication signal coverage in tunnels. The FM radio signal is transmitted through the cable and by virtue of the slots in the outer conductor, the signal is then radiated within the tunnel providing reception for in-car radio receivers. As the radio signal travels along the length of the leaky feeder, the signal strength diminishes due to the attenuation characteristics of the cable and due to the radio frequency energy being radiated into the surrounding environment. This is compensated for by placing repeater stations at intervals along the length of the cable and re-transmitting full power radio signal at these stations. The messages which are transmitted on the radio signal are delivered to the repeater station digitally on fibre optic cables which do not have the same attenuation problems as RF signals on co-axial cables.

The FM radio rebroadcast system in Dublin Port Tunnel rebroadcasts 7 of the approximately 15 FM stations available in the area by direct broadcast. The bandwidth of leaky feeders is very wide and does not represent a constraint on the number of channels that can be rebroadcast. A properly specified cable should have no difficulty in providing satisfactory signal strength for the PMR, emergency PMR and public radio systems required in Dublin Port Tunnel. The constraint on the number of channels rebroadcast is a function of the equipment installed in the control room and the equipment at the repeater stations along the length of the radiating cable. The addition of extra FM channels requires the installation of extra FM translators and fibre optic transmitters in the control room and corresponding fibre optic receivers and FM amplifiers at the leaky feeder in the tunnel. Currently available systems allow the rebroadcast of 15 FM stations, Four AM stations, two LW stations and 5 Digital Audio Broadcasting (DAB) multiplexes. The technology involved is mature, well understood and easily available. The limit of 7 stations seems arbitrary and unnecessarily restrictive in view of the mature nature of the technology involved and the availability of standard systems capable of rebroadcasting all currently available and foreseeable services.

3 Tunnel Communications Systems and the European DIRECTIVE 2004/54/EC

Tunnels are hazardous environments due in large part to their enclosed nature which increases the potential severity and risk of loss associated with accidents and which increases difficulty of evacuation and rescue. Fire is an extreme hazard in tunnels due to the rapid buildup of smoke, poisonous gases and heat that can
occur. Smoke can quickly fill the tunnel reducing visibility, making evacuation difficult and rendering CCTV monitoring systems useless.

The Mont Blanc and Tauern tunnel disasters which occurred in March and May of 1999 and resulted in the loss of 39 and 12 and lives respectively led to a Europe wide review of tunnel safety which resulted in DIRECTIVE 2004/54/EC of the EUROPEAN PARLIAMENT AND OF THE COUNCIL OF THE EUROPEAN UNION. This directive lays out the minimum safety requirements for tunnels in Europe and is based on the lessons learned from these disasters.

The Mont Blanc fire occurred in the middle of a transalpine tunnel between France and Italy when a heavy goods vehicle (HGV) transporting flour and margarine caught fire. The HGV was not involved in a collision and it is not known how long it took for the initial fire to transmit to other vehicles but 34 vehicles including 20 HGVs burned over a distance of more than 800m in a fire that lasted 53 hours and caused 39 deaths. A number of systems failures contributed to the high casualty rate. The fire detection system did not work. The CCTV camera images could not be used to locate the fire because of a trail of dense white smoke left by the damaged HGV for up to two minutes before it came to a stop and ignited. The ventilation systems were operated incorrectly causing accelerated smoke propagation. There were delays alerting the emergency services and when they arrived they could not reach the fire locations due to the dense smoke. Car drivers entered the tunnel after the fire had started in spite of red signals and sirens.

Two months after the Mont Blanc disaster another fire occurred in the Tauern transalpine tunnel in Austria. The situation in the Tauern tunnel was potentially more hazardous. Traffic levels were higher in the Tauern tunnel at the time of the accident. The fire was caused by a front-rear collision between several vehicles including an HGV transporting paint canisters. The fire spread quickly to other vehicles because the collision caused fuel to spill onto the roadway. During the fire, paint canisters carried by the HGV involved in the initial collision exploded. Some of the same systems failures that occurred in the Mont Blanc fire occurred at Tauern also. 12 people lost their lives in the Tauern fire including 8 who died in the collision itself. There are a number of factors which explain the lower death toll despite the potentially more hazardous circumstances including the location of the accident closer to one of the tunnel portals and the better operation of the ventilation system but the key difference appears to have been the behavior of the tunnel users.

- In the Mont Blanc Tunnel, 29 of the 39 victims were found in or close to their vehicles. Not realising the danger that they were in and not appreciating the severity or proximity of the hazard, many tunnel users remained in what appeared to be the relative safety of their vehicles and were overcome by the toxicity of the fumes and smoke from the fire. The
tunnel users in the Tauern Tunnel were aware of the previous Mont Blanc fire as it had featured in news media across Europe. They therefore knew to react quickly and flee and make their way to escape routes. According to reports into the Mont Blanc and Tauern disasters, a key lesson learned is the need to inform tunnel users of the safest behavior in the event of a fire or other hazards occurring. The importance of swift self-evacuation has been highlighted in accident reports of subsequent tunnel fires. Accident investigators of the fire which occurred in the St Gotthard alpine tunnel in Switzerland in 2001 estimated that the victims in that fire were trapped by smoke within 6 minutes and were dead within 12 minutes of the start of the fire. This is a shorter timespan than that within which the emergency services can respond to such disasters. Accident reports from other tunnel incidents emphasise the importance of self-evacuation as the single biggest factor in reducing the consequences of an accident once a fire has ignited. The need to persuade tunnel users to act appropriately is a key focus of emergency response; people must be convinced an emergency is genuine before starting to act. Direct messages can be very effective in initiating self-evacuation. It can be concluded that early and effective communication with tunnel users is an important safety control due to

- the speed with which tunnel hazards can escalate,
- the importance of early self-evacuation and
- the need to communicate directly with tunnel users to initiate self-evacuation.

With this context in mind, the communicating channels available to the operator of Dublin Port Tunnel to directly communicate with tunnel users consist of:

- The variable message boards which are suspended from the tunnel roof approximately every 450 metres and allow written messages to be displayed. In situations where traffic is stopped the effectiveness of the message boards is compromised due to their not being visible for much of the length of the tunnel due to their wide separation. In the event of a fire, reduced visibility due to smoke would reduce their effectiveness further.

- The public address system which allows audio messages to be broadcast via loudspeakers. The high ambient noise and the acoustic characteristics in road tunnels make satisfactory PA system performance difficult to achieve.

- The break-in facility on the Public Radio Rebroadcast system which allows the tunnel operator to override the signals received by in-car radios and to communicate directly with vehicle occupants. The general constraint of this system is that the car audio system must be on and switched to radio rather than CD or other source. In the case of the system implementation in Dublin Port Tunnel, there is the further constraint that the radio must be tuned to one of the limited number of channels that are rebroadcast. Currently available systems can take control of the in-car audio equipment,
switch it on, and switch it to the radio function allowing reception of the emergency message.

4 Provisions of DIRECTIVE 2004/54/EC relating to communication systems:

Under the heading ‘Communication Systems’, Section 2.16 of the Directive states:

- 2.16.1. Radio re-broadcasting equipment for emergency service use shall be installed in all tunnels longer than 1000 m with a traffic volume higher than 2000 vehicles per lane.

- 2.16.2. Where there is a control centre, it must be possible to interrupt radio re-broadcasting of channels intended for tunnel users, if available, in order to give emergency messages.

Annex 1 of this Directive lays out the minimum safety requirements required for road tunnels. Under the subsection ‘Communications Systems’, the following features are listed as mandatory for tunnels such as Dublin Port Tunnel:

- Radio re-broadcasting for emergency services.
- Emergency radio messages for tunnel users.

5 Risk Analysis taking into account design factors that may affect safety:

Article 13 of DIRECTIVE 2004/54/EC 3 requires that a risk analysis be carried out taking into account design factors that may affect safety.

Even the most basic of risk analysis which takes into account the constraints on controls available to the tunnel operator due to the limitations of the rebroadcast system will highlight the increased risk to the safety of tunnel users as a result of these limitations.

Figure 7 shows a systems engineering approach to representing one hazardous situation as part of a risk analysis which takes into account the communication system design factors that may affect safety.

It represents the following situation:

- An accident and fire has occurred in the tunnel.
- Traffic has stopped and backed up and vehicle drivers are waiting in their cars unaware of the reasons for the delay and the danger unfolding.
- The tunnel operator is aware of the danger via fire alarm or other feedback channels and has initiated the evacuation process.
- Smoke from the fire has reduced visibility making the Variable Message Boards ineffective.
- Fire Alarms, other ambient noise and reverberation make the PA system messages unclear.
- The Tunnel Operator uses the FM break-in feature to broadcast emergency messages instructing tunnel users to self-evacuate.
• Some tunnel users do not receive the emergency instruction to self-evacuate because they are not tuned to one of the limited number of rebroadcast FM stations.

This situation represents a systems failure because a control action required for safety is not provided or not provided fully.

Two out of three control channels, the Variable Message Boards and the PA system have failed due to factors arising from the hazard, namely smoke and noise. The third channel is a partial failure because of design factors. The rebroadcast system can only contact tunnel users tuned to a limited number of stations.

The consequence of this partial systems failure is the potential delay in the initiation of the evacuation process and an increased risk to tunnel users.

7 Conclusion.

The break-in facility of the FM rebroadcast system is an important safety control and communication channel in an emergency situation.

The simple risk analysis outlined above demonstrates the possibility of scenarios arising where the rebroadcast limitation reduces the effectiveness of control actions required for safety and consequently increases the hazard level.

An upgrade to the in tunnel communications system to enable safety messages to be broadcast on all licensed FM stations available in the area would increase the effectiveness of an important control channel required for safety and consequently reduce the hazard level. The cost of this upgrade would, according to industry sources, be relatively modest.

The limitation on the number of FM radio channels rebroadcast in Dublin Port Tunnel adversely affects the safety of tunnel users. The safety of tunnel users would be improved by upgrading the in tunnel communication system to enable safety messages to be broadcast on all licensed FM stations.
Figure 1. Location and route map of Dublin Port Tunnel.

Figure 2. North Portal of Dublin Port Tunnel.
SAFETY
Drive with dipped headlights on. Observe the speed limit. Tune into FM radio to hear any safety instructions.

TUNNEL OPERATOR
The Operator has full jurisdiction in the Tunnel. Drivers must obey instructions from the Operator.

FM RADIO BREAK-IN FACILITY
In case of an incident, tune into any FM radio station to hear safety instructions.

CCTV
CCTV is in operation throughout the Tunnel.

LOUDSPEAKERS
Loudspeakers and Electronic Variable Message Signs will be used to give instructions.

EMERGENCY STATIONS
Emergency Stations on the left side of the tunnel wall have direct telephone connection to the Operator and contain fire extinguishers.

PEDESTRIAN EXIT
You must exit the tunnel via the marked pedestrian cross passages when instructed to do so.

EMERGENCY LAY-BYS
There are four emergency lay-bys on the left side of the tunnel wall at a distance of 1 km.

FIRE FIGHTING
Firefighting niches with hydrants are placed every 125 m and hose reels every 60 m.

Figure 3. Tunnel safety features published by operators of Dublin Port Tunnel

Figure 4. Tunnel safety features published by Dublin City Council
Figure 5. FM rebroadcast system diagram.
Figure 6. Schematic of Leaky Feeder/Radiating Cable.

Figure 7. Scenario diagram showing control structure for evacuation initiation.

Figure 8. Diagram illustrating the evacuation process.