Mobile Coverage on European Railways

A Draft Report to the Glasgow-Edinburgh Collaboration

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SQWconsulting

Contents

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1: Introduction

1.1 This is SQW Consulting's report of a research study for the Glasgow-Edinburgh Collaboration which has identified situations where mobile phone coverage has been improved on European railway tunnels and cuttings. As well as railway tunnels and cuttings, the study has identified a number of examples of metro systems and road tunnels which have also seen improvements to the mobile coverage available.

1.2 This research has been designed to inform the Glasgow-Edinburgh Collaboration of the type of solutions which are available to improve the quality of mobile phone reception on the Glasgow-Edinburgh rail link which suffers from poor reception at a number of points.

1.3 There are considerable benefits in improving the mobile reception on the Glasgow-Edinburgh rail link; SQW Consulting's 2007 'Wireless on the Move' study showed that improving voice connectivity would result in time savings of around £0.4 million per annum by 2011/12.

1.4 As well as ensuring that passenger time spent on the Glasgow-Edinburgh rail link is more productive, there are benefits for the MNOs and rail authorities of providing improved mobile coverage along the route. For the train operator, there are clear reputational benefits of providing uninterrupted service for customers, particularly the higher value business customers who regularly use the Glasgow-Edinburgh rail link. For the train operator, improved coverage can differentiate them from alternative forms of transport such as the private car and can add value to passengers' journeys therefore attracting new passengers and retaining existing passengers.

1.5 More generally, improvements to the passenger experience on the Glasgow-Edinburgh rail link can help to generate "environmental, reputational and quality of life benefits associated with a modal shift from the road to rail and an increase in the attractiveness and quality of Scottish rail travel."[1]

1.6 This report provides 15 brief case studies which outline the different technologies available to improve mobile coverage in tunnels and the main companies involved in the provision of these improvements. The case studies have been identified following an extensive web search of relevant company websites, project websites, MNO and railway operator websites, as well as industry news websites such as cellular-news.com, railnews.co.uk, zdnet.co.uk and computerweekly.com. In addition, a thorough search of the 'Business and Industry' database, which contains articles on companies, industries, products and markets from over 1,000 international trade and industry publications was undertaken. This desk research has been followed up by phone consultations with as many of the companies involved as possible to gain further details on the case studies. The key consultees are shown in Table 1-1.

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[1] SQW Consulting, *Wireless on the Move,* 2008

Table 1-1

Consultee	**Position**	**Company**
Mark Balfour	Account Director	Arqiva
Ian Finch	Sales Manager	RFS
Markus Kalt	VP Business Operations EMEA, Wireless Innovations Group	Andrew Corporation
Peter Moody	Business Area Manager	Axell Wireless
Steve Leach	Chief Technology Officer	Red-M
Amit Seth	Senior Systems Design Engineer	First Co

Source: SQW

2: Case Studies

Case Study 1

Name: Gotthard Pass

Date of implementation: Completion is estimated at 2015, but this timescale may slip due to problems with unstable and soft rock.

Railway company: Swiss Federal Rail Company

Mobile network operator(s): Installed platform for mobile communications open to the mobile network operators

Location of implementation: along the Gotthard Pass – covering two single track lines of 57km each, plus 11km over-ground to the North and South. The equipment is installed in cross-tunnels that are located every 100m along the tunnels.

Site details: the Gotthard pass, once completed will be the longest tunnel in the world at 57km. There is an existing tunnel that is not so deep, that is restricted in terms of the weight and speed of trains supported. The full depth of the tunnel is not known, but it is reaching beneath mountains of over 3,000m above sea level. Difficulties have been faced in the tunnelling due to encountering a section of unstable and soft rock. It is not known whether there have been particular difficulties facing the installation of communications.

Equipment suppliers: Transtec Gotthard is a consortium composed of leading rail technology partners: Atel, Alcatel-Lucent / Thales, Alpine Bau and Balfour Beatty Rail. Alcatel-Lucent is the communications supplier.

Overview of technical solution: GSM 900/1800 and UMTS coverage has been provided by using Andrew Corporation's ION-M amplifier system.

Rationale for implementation? The mobile in-fill is referred to in the coverage of the project as an additional element of a large scale implementation. Potentially for a tunnel this large, even given the new high speed trains to be deployed on the route, passengers would be without mobile coverage for some 13 minutes, which is not acceptable to passengers (particularly those that may be uncomfortable travelling in tunnels given the fatal accidents that occurred in the Gotthard road tunnel in 2001).

Indicative costs: part of a wider EUR1.05bn contract to install railway infrastructure, power supply, signalling, communications for operational use. Also included enhanced GSM coverage for

Costs borne by MNO, railway company, other, shared: this is being borne as a total solution in the tunnel. The MNOs are not making an investment in the infrastructure. There will be one set of infrastructure to be installed in the tunnel, which will be shared between MNOs as they wish to sign up. We have not yet seen any commercial terms under which this might work.

Case Study 2

Name: Arlanda Express

Date of implementation: 2005

Railway company: A-Train AB

Mobile network operator(s): 3 Swedish mobile operators

Location of implementation: Along the 40 kilometre Arlanda Express rail link between Stockholm city centre and Stockholm's Arlanda International Airport. Five kilometres of tunnels to the North and South of the Airport have been covered.

Site details: The Arlanda Express rail link includes a total of 9.2 kilometres of tunnels and 3 underground stations.

Equipment suppliers: Powerwave had responsibility for designing, commissioning and optimizing the GSM 900 system. Giving one firm full responsibility was designed to save network operators time and effort in coordinating the project.

Overview of technical solution: Powerwave provided a fibre optic repeater system which gives each operator access and remote monitoring capabilities. This involved three key elements:

- *The Base Station Site* (BTS) site comprised of BTSs owned by three operators, as well as one shared Powerwave Base Station Master Unit (BMU). The BTS's fed the antennas covering the area around the site, as well as radiating cables covering the tunnel portions adjoining the site. A small fraction of outgoing power from each BTS was fed into the BMU, where RF signals were converted to laser light. Optical signals were distributed to several repeater sites inside the tunnels through a joint fibre optic network.
- *Fibre Optic Distribution* was used for signal distribution allowed swift, economical expansion of the system, without creating difficulties relating to availability of transmission, donor signal strength, or antenna isolation.
- *Repeater Sites* were comprised of one repeater for each operator, containing the unit that converts optical signals back to RF. The RF signals were then fed to the corresponding repeaters where they were amplified and redistributed independently to antennas covering platforms and stairways, and to the radiating cable covering the tunnels. Distance between repeater sites was approximately 1.1 km.

Rationale for implementation? Seamless GSM coverage for passengers travelling to and from the airport by Arlanda Express is of great importance to three of the Swedish mobile operators.

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: All three network operators share the entire optical distribution network, including fibre, BMU, and optical-to-RF conversion units, thus minimizing initial investment and operating costs.

Additional savings are realised because the system has been designed to employ only two fibres for the entire repeater network - one for downlink, the other for uplink.

Case Study 3

Name: SPT Underground

Date of implementation: December 2008

Railway company: Strathclyde Partnership for Transport

Mobile network operator(s): O2 with other operators interested

Location of implementation: Glasgow Subway network

Site details: Arqiva's 2G and 3G and WiFi provides coverage at the following five main stations within the Glasgow Subway network: Buchanan Street, St Enoch, Hillhead, Partick and Govan. This solution includes the ticket areas, walkways to the platforms and the station platforms and provides contiguous coverage from the station entrances to the platforms. However, the tunnels between the stations are not covered by the coverage improvements. Coverage can be extended to cover the other 10 subway stations and the adjoining tunnels at a later date if demand is sufficient.

Equipment suppliers: Arqiva built, own and operate the system. Andrew provided the ION™-M distributed antenna system, a robust high power-density optical fibre distributed antenna system that offers excellent performance in both indoor and outdoor environments

Overview of technical solution: The Glasgow Subway coverage solution is based on active DAS technology with the BTS/Node-B equipment being located in the existing Arqiva CityCell BTS equipment room in Cowcaddens.

Rationale for implementation? According to Derek McManus, O2 Chief Technology Officer, "This new technology will enable customers to make calls, send and receive text messages and access a host of data services while on the subway platform. This is the first time that any mobile phone network in the UK has implemented a service like this and O2 is delighted to be giving its customers the first chance to communicate on the underground.

"Ultimately, this is about providing O2 customers with the best customer experience and if this means that they can continue conversations on underground platforms or can text friends to say that they'll be arriving in five minutes, then we've successfully provided a better service."

Indicative costs: Commercially sensitive

Costs borne by MNO, railway company, other, shared: Commercially sensitive

Case Study 4

Name: German High Speed Train (ICE)

Date of implementation: April 2008 – 2010

Railway company: Deutsche Bahn

Mobile network operator(s): German mobile network operators T-Mobile, Vodafone, the E-Plus Group and O2.

Location of implementation: Germany

Site details: Andrew in-train repeaters will be installed in all 250 ICE train sets covering nearly 1,500 carriages—the majority of the ICE fleet—that will feature high quality, high-availability mobile telephony signal coverage for passengers and official rail communications.

Equipment suppliers: Andrew

Overview of technical solution: The Andrew repeater system will support five separate GSM networks, covering the four operators plus the rail system's communications network, in the GSM-900, GSM-1800 and GSM-R bands.

Rationale for implementation? According to one consultee, there are a number of reasons for installing coverage in tunnels and underground are three-fold:

- The MNOs like to have a complete network with as near 100% coverage as possible as it is very positive from a marketing point of view
- Some evidence that it is profitable as customers have limited options when travelling and may use their phone more than usual, therefore increasing profits for the MNOs

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: in the majority of cases, the costs of these types of investments are shared by the MNOs who may also have to pay the railway company for allowing them to install equipment on land owned by the railway operator.

The main reason that costs tend to be shared between the MNOs is that if one firm installs their own system, the other MNOs will follow suit. With limited space in tunnels and cuttings, this does not make sense from the railway companies perspective and sharing the system also lowers costs for the MNOs.

Case Study 5

Name: Football World Cup 2006

Date of implementation: 2006

Railway company:

Mobile network operator(s): Most of the major operators in Germany contracted these systems

Location of implementation: As well as providing wireless indoor solutions at nine of the World Cup stadiums, wireless solutions were also provided for several metro railways in World Cup cities including Stuttgart, Cologne, and Hamburg.

Site details: Locations across Germany

Equipment suppliers: Andrew designed, supplied, and installed single- and multi-carrier indoor coverage and capacity systems.

Overview of technical solution: Andrew provided optical multi-operator/multi-band systems of considerable size for distribution of wireless signals down tunnels and throughout stations.

Andrew's ION™-M distributed antenna and repeater system was the coverage and capacity distribution solution chosen by most of the wireless operators for these World Cup-related projects.

This system supports the GSM900, GSM1800 and UMTS frequency bands. The ION-M's flexible design and high power output resulted in easy customisation to the unique spatial requirements of each stadium and railway.

The systems' basic architecture involves fibre optic and coaxial cables, master and remote units, and other subsystem products that receive and transmit signals from dedicated operator base transceiver station radio equipment to customer handhelds throughout the metro system, and vice versa.

Rationale for implementation? The 2006 World Cup in Germany brought tens of thousands of football fans to stadiums in various German cities, all with the expectation that their mobile devices will operate perfectly.

To meet these high expectations for network usage, most German wireless operators were keen to ensure that the indoor coverage and capacity distribution systems which were needed to support the high volume of wireless traffic expected at the tournament were put in place.

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: shared by the MNOs

Case Study 6

Name: Turin Metro

Date of implementation: The first phase, completed in December 2005, covers the underground locations that were most heavily by visitors to the 2006 Olympic Games. Completion of the second and final phase was completed in summer 2006.

Railway company: n/a

Mobile network operator(s): TIM, Vodafone, Wind and 3 Italia

Location of implementation: Turin Metro

Site details: The Turin Metro includes 16 stations and 9.5 kilometres of tunnels

Equipment suppliers: Andrew is responsible for management of the entire project, including site survey, coordination among the four operators, installation, testing, and commissioning.

Overview of technical solution: The two-phased project includes EGSM900, GSM1800 and UMTS coverage for commuters at any of the underground's 16 stations and on trains travelling up to 80 kilometres per hour anywhere between the stations.

The Andrew ION-M systems being deployed include tri-band GSM/UMTS remote units and antennas for the stations and tunnels.

Rationale for implementation? In expectation of the increase number of underground users who attended the Turin Winter Olympics in 2006.

The mobile operators provided this improved coverage to increase service quality to their customers and also for safety reasons.

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: Shared between the operators

Case Study 7

Name: Intercity Express Railway Tunnels

Date of implementation: The communications project began in late 2001, and was completed in late summer 2002.

Railway company: Deutsche Bahn

Mobile network operator(s): T-Mobile, Vodafone, and E-Plus

Location of implementation: The 226 kilometre Intercity Express (ICE) high-speed rail line between Cologne and Frankfurt, Germany.

Site details: The ICE high-speed rail line between Cologne and Frankfurt ran its first service in August 2002 and became fully operational on 15 December 2002.

Equipment suppliers: Andrew Corporation

Overview of technical solution: The ICE's new frequency-optimized slotted communications line supports all three European mobile communication bands: GSM 900, GSM 1800, and UMTS. Andrew developed and supplied over 47 km of wireless infrastructure for multi-band communications distribution covering the 30 new tunnels along the ICE line.

The tunnel communications systems use Andrew Corporation's RADIAX® RCT7-CPUS-2-RN radiating coaxial cable. This cable has specially-designed slots in the outer conductor that effectively radiate and receive the wireless signal along the entire length of the cable, creating uniform RF coverage that supports mobile communications in tunnels. An earthing and installation concept – created specially for the ICE – minimizes signal interference caused by high current fluctuations associated with high-speed train operation.

Rationale for implementation? With journey times for the 226 km (140 mile) trip between Frankfurt and Cologne at around 2hr 15min, it's expected that passenger numbers will reach 20-25 million by 2010.

In response to requests from mobile operators, Andrew Corporation's Wireless and In-Building Products Group developed a new multi-band wireless infrastructure for giving commuters clear wireless phone reception in tunnels along the newly-opened ICE high-speed rail link between Frankfurt and Cologne.

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: the costs of the installation were shared across the MNOs.

Case Study 8

Name: Hamburg Subway

Date of implementation: 2003 - 2006

Railway company: Hamburg Hochbahn

Mobile network operator(s): Vodafone, T-Mobile and O2

Location of implementation: Hamburg Subway

Site details: This project provided coverage in all of the tunnels as well as the 39 stations.

Equipment suppliers: RFS World

Overview of technical solution: By using RADIAFLEX cable—which simply functions as a distributed antenna system—consistent and premium coverage is realised in the tunnel and at all stations. The colour of the cable has been adapted to the stations, and most importantly, the RADIAFLEX cable is fire-retardant—a crucial aspect when it comes to in-tunnel security.

Rationale for implementation? The Hamburg Hochbahn hopes to get more satisfied customers by offering better in-tunnel coverage. According to Gernot von Bargen, project manager at Hochbahn: "It is a bonus for us that our passengers can use their mobiles without any interruptions while travelling in the subway. But not only our customers benefit from this investment—the digital radio services of the Hochbahn, police and fire department can also make use of the new network"

Indicative costs: Total cost of six million Euros

Costs borne by MNO, railway company, other, shared: Shared between mobile operators and the railway company

Case Study 9

Name: Metro Budapest

Date of implementation: 2005

Railway company: Metro Budapest

Mobile network operator(s): Vodafone Hungary

Location of implementation: Metro Budapest

Site details: Included 32 stations

Equipment suppliers: RFS World

Overview of technical solution: The new communications system supports Vodafone Hungary's global system for mobile communications (GSM) services in the 900-MHz and 1800-MHz bands, plus third-generation (3G) universal mobile telecommunications system (UMTS) services.

Based on its longitudinal attenuation and coupling loss performance, RFS's broadband RADIAFLEX RLKU cable was selected to provide coverage for 32 metro stations. Furthermore, the cable jacket features a guide to ensure the cables are installed with the radiating slots at the correct orientation. This saved Vodafone Hungary valuable installation time.

For some sections of Metro Budapest, the RFS RADIAFLEX RLVU cable was deployed. This cable is specially designed to operate over longer transmission lengths without need of amplifiers. The service length of a cable can be increased by decreasing coupling loss gradually to the extent necessary for compensating longitudinal loss. In the RLVU cable, this is achieved in stepwise fashion, where the cable consists of sections of decreasing coupling loss.

In the case of metro tunnels where access may be limited, the ability to use longer lengths of cable, thereby minimizing the use of active equipment, significantly eases system maintenance. Additionally, both the RADIAFLEX RLKU and RLVU cables are fully broadband, able to support multiple services from TETRA 380 MHz up to UMTS 2100 MHz.

Rationale for implementation? not known

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: not known

Case Study 10

Name: Trojane Tunnel

Date of implementation: 2005

Railway company: ***n/a***

Mobile network operator(s): Mobitel

Location of implementation: Trojane Tunnel, Slovenia

Site details: On the 12th August 2005, the Trojane – Blagovica section of the 230 kilometre A1 motorway between Maribor in the east and Koper in the west was officially opened. This 8.2 kilometre section included the Trojane tunnel, which at 2.9 kilometres is Slovenia's longest double-tube tunnel.

Equipment suppliers: Mobitel

Overview of technical solution: Mobitel provided an uninterrupted signal and the option of using GSM services on the route of the new motorway, including the Trojane and Podmilj tunnels.

At the same time all requirements for the activation of UMTS stations were met, and they will be activated immediately after the completion of the entire chain of Mobitel's UMTS stations on route of the Ljubljana – Maribor motorway. Mobitel also completed the coverage of tunnels in the Primorska motorway leg.

Rationale for implementation? The provision of mobile phone coverage in the Trojane and Podmilj tunnels allows Mobitel's users uninterrupted use of mobile telecommunication services in the entire motorway cross between Maribor and Koper.

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: not known

Case Study 11

Name: Lefortovo Tunnel

Date of implementation: 2004

Railway company: n/a

Mobile network operator(s): Mobile Telesystems (MTS)

Location of implementation: Lefortovo and Gagarin Tunnels, which together form part of Moscow's recently completed Third Ring Road, a bypass connecting the central districts of the city.

Site details: The Lefortovo tunnel, which funnels cars through the Lefortovo district of Moscow, consists of three tunnel sections. The longest is almost three kilometres in length, while the other two sections are each around one kilometre long. Opened in 2003, the tunnel system was expanded in 2004 to become one of the most complex in the whole of the city.

Equipment suppliers: RFS World

Overview of technical solution: Four base stations located within the Lefortovo tunnel system support GSM900 cellular services. Two different types of RADIAFLEX foam-dielectric radiating cable for this project, ensuring excellent network coverage: around three kilometres each of RADIAFLEX RLKU and RLV cable were laid throughout the entire tunnel system. Owing to its broadband capability, a single RADIAFLEX cable can handle multiple communication systems simultaneously, and can also be used for uplink and downlink simultaneously.

Installation of the RADIAFLEX cables afforded MTS and its customers a number of advantages. "The cable features flame-retardant and fire-retardant jackets, and the real coverage provided corresponded precisely to the measured forecast coverage. In addition, the excellent choice of mounting hardware, allowing the various cables to be laid with an extremely accurate fit in the tunnels, was a very persuasive argument in favour of the system," according to Sergey Vorobiev, responsible for the Lefortovo Tunnel project at MTS.

Rationale for implementation? To allow drivers on Moscow's Lefortovo and Gagarin road tunnels to make and receive cellular calls

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: not known

Case Study 12

Name: Switzerland's rail tunnels

Date of implementation: Project commenced in mid 2002

Railway company: Swiss Rail

Mobile network operator(s): not known

Location of implementation: Switzerland's 700 rail tunnels. These vary in length from one kilometre to 57 kilometres.

Site details: The first of two recipients of the new confined coverage system in 2002 was the 'Rothrist - Mattstetten' tunnel between Zurich and Bern.

Equipment suppliers: Comlab conducted the installation and RFS World provided 300 kilometres of radiating cable.

Overview of technical solution: To ensure reliable performance with low coupling loss for each tunnel, Comlab has selected RFS RADIAFLEX RLKU radiating cable. The cable provides coverage for all frequencies from 380 MHz to 2200 MHz, and will support the later accommodation of TETRAPOL, one of the European public safety systems as well as UMTS.

Rationale for implementation? Swiss Rail has responded to requests from both mobile operators and the general public with plans to provide coverage for global system for mobile communications

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: Swiss Rail were the main customer for this project

Case Study 13

Name: Madrid Metro

Date of implementation: July 2001

Railway company: Madrid Metro

Mobile network operator(s): Telefonica, Airtel, Amena, and Dolphin

Location of implementation: Madrid Metro

Site details: The system provides improved wireless communications for the Madrid Metro's existing Mar de Cristal, Campo de las Naciones, Barajas Aeropuerto (Madrid's International Airport), and Barajas Pueblo stations and their adjoining commuter tunnels. These stations are along Line 8, one of the Metro's busiest commuter lines, bringing around 42,000 travellers a day from the airport to the city centre.

Equipment suppliers: Andrew Corporation was responsible for the total RF design, testing and integration of the system from the point of interface between the base transceiver stations to the mobile phones, while ISOLUX Wat was responsible for installing the system according to the requirements of the Madrid Metro. Metrocall, the joint venture between the Madrid Metro and the Tecnocom Group, will operate the common underground cellular infrastructure.

Overview of technical solution: A distributed communications system was used to support TETRA and GSM 900/1800 communications within the public areas of the airport line metro stations and adjoining running tunnels. The system was designed so that it could also be upgraded for UMTS technology.

The Madrid Metro distributed communications system will include almost 20 kilometres of Andrew new tuned RCT7-LTCPUS RADIAX(R) radiating coaxial cable, 19 fibre-fed amplifiers, and 4 base station combiners.

Rationale for implementation? With traffic congestion gradually getting worse, creating deteriorating air quality and increased traffic noise, the expansion of the Madrid Metro is seen as an important part of the solution. By extending and creating lines and new stations and providing better communications for the safety and convenience of passengers, the Metro is helping to encourage modal shift away from cars in favour of public transport, in particular the Metro system. The new distributed communications system plays a critical part in making commuting on the Madrid Metro a safe, comfortable, and convenient experience.

Indicative costs: Improved communications are part of a $1.4 billion scheme that was begun in 1995 to extend the network and create new lines and stations equipped with the latest technological advances for the safety and comfort of metro travellers.

Costs borne by MNO, railway company, other, shared: not known

Case Study 14

Name: Coverage in Italian rail tunnels

Date of implementation: 2003

Railway company: Group Ferrovie dello Stato

Mobile network operator(s): TIM (negotiations are also in progress with other mobile telephone operators)

Location of implementation:

Site details:

Equipment suppliers: TIM installed dedicated masts to optimise the coverage of its own GSM network and allow its customers to use their mobiles in tunnels and over the entire railway network. In order to allow for clear reception in the tunnels along the rail network, RFI installed equipment to amplify the radio signal.

Overview of technical solution:

Rationale for implementation?

Indicative costs: not known

Costs borne by MNO, railway company, other, shared: not known

Case Study 15

Name: Lainz tunnel

Date of implementation: 2008

Railway company: ÖBB

Mobile network operator(s): not known

Location of implementation: Lainz tunnel and the Purkersdorf switch hall, Austria

Site details: as of 2012, the Lainz tunnel will provide an efficient connection between the Western railway line and the Southern and Donaulände railway lines. The Purkersdorf switch hall will connect the Lainz tunnel and the new Vienna-St. Pölten line with the Western line.

Equipment suppliers: Kapsch CarrierCom AG

Overview of technical solution: This project involves the deployment of wireless digital systems in the Lainz tunnel and the Purkersdorf switch hall.

In addition to providing GSM-R based Public Safety services, the radio system in the Purkersdorf switch hall will also provide analog wireless train communication and private mobile radio services. Furthermore, the order also includes the integration of a TETRA system, the Vienna fire department wireless communication system and an automated track gang warning system.

While the radio system in Purkersdorf will primarily improve logistics, the Lainz tunnel project will also benefit ÖBB's passengers because GSM900/1800 and UMTS connections will also be provided in the tunnel.

Rationale for implementation? The installation of UMTS and GMS900, GMS1800 and UMTS will provide passengers with uninterrupted calls and internet access during their journey.

Indicative costs: €1.3 million

Costs borne by MNO, railway company, other, shared: not known

3: Conclusions

3.1 This research has identified 15 case studies from ten countries, ranging in scale from relatively small projects covering a single rail tunnel to projects covering entire metro systems or the largest rail tunnel in the world.

3.2 Despite the wide range of geographies and situations where mobile coverage has been improved, there is a fairly standardised suite of technologies available to implement these improvements.

3.3 Radiating cable, also known as leaky feeder cable is used in six of the case studies. This cable is effective for rail tunnel applications because it acts as a continuous distributed antenna. Coverage can be achieved as slots are cut into the outside of the cable which allows a controlled portion of the internal RF energy to be radiated into the surrounding environment. Conversely, a signal transmitted near the cable will couple into the slots and be carried along the cable length. This means the signal can travel to and from the mobile phone along the entire length of the tunnel or cutting.

3.4 The second main technology which is used is based on repeater or amplifier technology whereby the signal is relayed from a base station to remote units inside the tunnel. This technology is used in six of the case studies. A further case study uses in-train repeaters whereby the repeater strengthens the mobile signal both into and out of the train carriage.

3.5 These technologies used in the case studies are provided by a number of key suppliers including Andrew Corporation and RFS World. Another prominent player in this industry is Axell Wireless.

3.6 Although the costs of individual have proved difficult to obtain, it is clear that the mobile network operators are keen to collaborate. Eight of the case studies identified more than one MNO and negotiations are on-going in a further two case studies to increase the number of MNOs involved.