PUBLIC CARRIER COMMUNICATIONS TECHNOLOGIES AND STRATEGIES FOR LOW TRAFFIC LINES

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SUMMARY

Australian railways have very low traffic densities on long routes. On many lines the traffic density does not justify a railway owned communication system so public carriers are used for both fixed and mobile communication. There is nothing new about using public carrier services in such situations – both fixed and mobile services been used for many years with substantial success. Soon the majority of Australian freight and country passenger services will use public carrier services for mobile communication.

Public carriers do not set out to provide reliable communications infrastructure for safety critical systems. They set out to optimise the profitability of their infrastructure. Can a railway rely on such a system for its operation? We review some technical and operational considerations.

Australian railways have resolved some of the technical and operational issues creatively. The most significant of these systems are described, along with the particular requirements of off-train communications.

1 INTRODUCTION

1.1 Geography, Population and Railways

Australia is the world's largest island and the world's smallest continent. Its population of 20.4 million is concentrated on the coastal fringe of the continent. Most people live in the cities and the passenger rail transport task is primarily within the cities. As there are no high-speed passenger services, air travel is the preferred means of transport between cities and to regional centres.

Rail freight in Australia is primarily used for long haul, mineral and grain traffic. Containers are freighted by rail between the major cities but for most of the routes road transport is cheaper end-to-end.

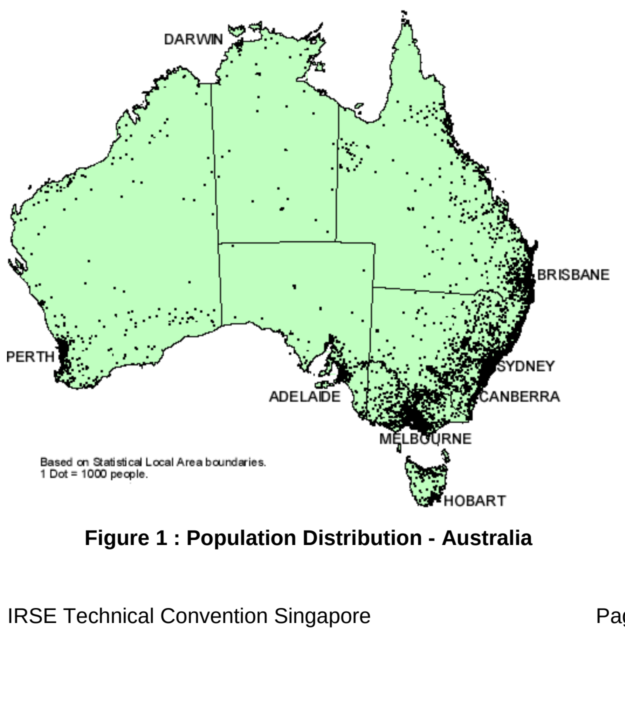

Figure 1 : Population Distribution - Australia

Figure 2 : Australian rail routes

Figure 2 shows the rail routes. The majority of rail traffic is on the lines that link the capitals and on the coal and ore lines. A substantial number of lines have low traffic – less than ten trains per day. Many of these have less than one train per day and some are seasonal, being primarily for grain traffic.

With very few trains on most lines, there is a correspondingly small income for those lines. On many the traffic does not justify a railway owned communication system so public carriers are used. Both satellite and cellular telephone networks are now used by a number of operators. Satellite services have been employed by one railway for over ten years.

1.2 Australasian Railway Association

The Australasian Railway Association is an industry body that seeks to coordinate railway activity and to lobby governments. It has recently taken an interest in communications and has set out a strategic framework for communications[1]. It recommends that any future voice and data communication systems be:

- nationally interoperable and compatible
- based on standards that support a multi-vendor competitive market and interoperability
- capable of supporting new and emerging train control systems
- able to support the safety and business needs of track managers and train operators
- capable of operating on both owned and public communication transmission networks, across the entire range of rail networks
- able to provide a guaranteed level of access to service
- able to achieve reliability and maintainability targets
- able to provide the required degree of resilience and survivability
- capable of facilitating secure and authenticated operation
- supplemented with fallback communications means in the event of the primary system failing or becoming degraded.

The Australasian Railway Association member railways are not bound to these recommendations and have not adopted them uniformly.

1.3 Communications Carriers

The Australian railways were innovators in communications in the 1800's and in fact offered the first public telegraph services. Since those times railways have become users of public communications rather than providers.

Three mobile/cellular telephone service providers dominate the market in Australia. They offer GSM and CDMA cellular services over the majority of populated areas and third generation cellular networks in the cities. The carriers claim to cover 98% of the population. This certainly does not equate to 98% of the railway line.

The satellite mobile telephone services available in Australia are:

- ***Mobilesat*** – a geostationary satellite system primarily serving Australia and in extensive use by Australian railways
- ***Globalstar*** – an international Low Earth Orbit satellite service that is available in some dual mode handsets.
- ***Iridium*** – the revived Low Earth Orbit service
- ***Inmarsat*** – global geostationary services and future Low Earth Orbit services.

The range of public services is adequate and in most locations there is competition between carriers. However, the total rail user base is insignificant for all but the Optus Mobilesat system. Rail is a major user of Mobilesat.

2 NOTATION

ASW - Alternative Safe Working system – a communication based train control system using movement authorities transmitted as data messages over mobile radio and displayed on a screen. Implemented only in the state of Victoria.[2]

CDMA - Code Division Multiple Access – a cellular telephone technology that uses spread–spectrum techniques.

GSM – Global System for Mobile communication – a cellular telephone technology that uses time division multiplex techniques. GSM is the most widely used cellular telephone technology.

GSM-R – A railway specific set of enhancements to GSM. GSM-R is defined by international standards.

GPS – Global Positioning System – uses a constellation of low earth orbit satellites for position determination.

NSW – New South Wales – a state of Australia. Its capital city is Sydney.

PABX – Private Automatic Branch Exchange – a telephone exchange that provides private telephone services but is also connected to the public network (hence branch exchange).

SIM – Subscriber Identity Module – the SIM is a detachable smart card containing the user's subscription information and phonebook.

PTT – Push To Talk – pressing a button activated the mobile radio transmitter for speech.

3 MOBILE SYSTEMS

3.1 Train Radio Features

Train Radio systems have a range of features. Many of these features are common to all mobile radio systems but others have been developed specifically for railways. The features include:

- ***Emergency call*** with rapid connection. This feature may be achieved through open channel operation, where everyone affected can hear the conversation and where the emergency situation is conveyed by procedures (announcing "emergency").

  In systems that do not have open channel operation the emergency call is usually indicated by an alarm tone and a specific display to the train controller. Some “private” or “closed” systems broadcast the emergency call to all trains in the vicinity of the emergency. This is a very effective method of limiting damage after incidents or derailments.

- ***Normal Call.*** This may be an open channel call, as in most of Australia, or a private call, as used in New South Wales. The normal call has lower priority than an emergency call and, in many systems, will be disconnected if an emergency call is made.
- ***Broadcast Call***. A broadcast call is a one-way call from the train controller (usually) to all trains in the area. A broadcast call will be used to advise of special conditions and to provide general information. It may also be used after an emergency call. Broadcast calls are inherent in open channel systems.
- ***Group Call***. A group call is similar to a broadcast call but allows all parties to speak. Usually only one mobile can transmit at a time.
- ***Position Report***. Train radio systems in NSW (Countrynet area) and Queensland include a GPS position report in every radio call. In NSW a position report is transmitted regularly, in addition to the reports with each radio call.
- ***Short Data Message***. Some systems permit transmission of short data messages. The messages may be displayed to the driver as text or as a status indication. The NSW Metronet and the Victorian ASW systems have this facility. (It is included in Countrynet but has never been made available to the driver).
- ***Data Transmission***. The NSW systems (Metronet and Countrynet) have provision for transmitting long data messages or files. These facilities have never been used.
- ***Shunting***. Some UHF systems have special channels and procedures for shunting. GSM-R has a shunting mode that includes continuous call connection so that the users can be assured that they are in contact. Voice procedures are used in other systems to provide confidence that the crew are in contact with each other.
- ***Local Call***. Nearly all systems provide a local call facility. A local call is intended to cover the area around the train and is required to have open channel operation. The purpose of the local call is to provide immediate access to other trains and track maintenance staff. Open channel systems do not usually have a separate “local” channel, as they use the base station to cover the track with a talk-through repeater.

3.2 CDMA And GSM For Train Radio

CDMA and GSM are not designed as train radio systems and lack the majority of the train radio functions. The recently introduced push-to-talk (PTT) version of CDMA and GSM has some of the features, but with limitations.

Standard GSM and CDMA do not provide for call prioritisation[3]. An emergency call on CDMA is given priority only if it is addressed to “000” and is to be connected to the police, ambulance or fire services. Emergency calls to train control have the same priority as all over calls and may be blocked by other traffic in the call area.

Broadcast, group and local calls may be made in CDMA if the Push To Talk (PTT) function is used. However, the broadcast and group calls may only be made to known users. The phone numbers for these users must be programmed into the caller’s telephone. The systems currently in use in Australia permit only five phones to be included in a group call. Unless some changes are made to the system, the CDMA group call is not usable as an open channel system in railways. (One approach would be to dynamically reprogram the user’s SIM cards as the train moves, as can be done in GSM-R.)

Figure 3 : CDMA telephone cradle and mobile radio transceivers on an ARG locomotive

CDMA excels in handling data calls and short messages. GSM offers excellent short messaging but less flexible data calls. Short messages do not have guaranteed delivery.

CDMA and Railways

There has been a strong movement toward CDMA by some railway managements in recent years. A major infrastructure provider has stated that CDMA provides a safe communications medium and has obtained government funding ($60 million) to sponsor additional CDMA coverage along certain railway routes.

Is CDMA inherently an adequate or suitable solution for train radio? It is certainly a lot better than nothing – the alternative in many areas. However, CDMA does not have guaranteed connection and many of the new voice features (such as push-to-talk groups) that have been enthusiastically sold to the railways have been found to be lacking in functionality.

There is obvious scope for an engineered approach to the situation, where the issues and capabilities of the system are identified and solutions found. WestNet Rail is engineering the CDMA solution by ensuring that the railway has procedures and practices for measuring and auditing coverage. In addition, the railway is assessing the service reliability and providing backup systems for single person train operation. The backup systems are generally satellite services.

3.3 Satellite For Train Radio

Satellite telephone services are certainly not designed as train radio systems. They provide basic voice services with some data transmission, usually at limited speed. Low earth orbit satellites have the advantage of minimal transmission delay. For most users the delay is not perceptible.

Mobilesat and other geostationary services (where there is a single satellite in geostationary orbit above the equator) have significant transmission delays.

There is no provision in the satellite telephones for broadcast or group calls. The PTT services that are appearing on GSM and CDMA have not been offered for satellite systems.

Despite all these issues, satellite mobile telephony has been adopted for railway applications and has been used with great success.

4 COUNTRYNET – FIRST SATELLITE

4.1 Background

In the early 1990's the New South Wales government railways went through one of their many reorganisations. In this particular change the metropolitan passenger operations were split from the freight operations that were the dominant activity outside the Sydney metropolitan area. The new freight organisation "Freight Rail" was required to operate on a commercial basis, rather than as a subsidised government railway.

Mobile radio communications were very limited in the freight areas at that stage so one of the challenges was to provide reliable communication that would be affordable. After analysis it was clear that the majority of the track (some 5,000 km) could not support the cost of any mobile radio infrastructure. Only on track with more than ten trains per day could any infrastructure be considered.

The Freight Rail communications engineer, Mr Fred Rhodes, had the foresight to propose satellite telephone as the solution for the 5,000 km that would otherwise not have mobile communication. This was a revolutionary idea. At that time there was no domestic satellite in Australia and the Inmarsat systems required antenna sizes and gains that were impractical for locomotives.

Mr Rhodes and the author developed a communication system called CountryNet, which implemented a low-cost terrestrial system for the higher traffic lines and a satellite telephone service (using the then yet to be constructed) Optus Mobilesat system for the remainder of the track. This approach provided a satellite system overlay for the majority of the higher traffic lines, so redundancy was provided at no extra cost.

4.2 Locomotive Equipment

Countrynet locomotives are equipped with both terrestrial and satellite transceivers. A single interface is provided for the train driver, with simple button selections.

Telephone dialling and radio channel selection are controlled by GPS position data. Locomotive position reports are transmitted regularly through the system, using a very short (compacted) data message on the satellite. (This was the first full application of GPS in a railway.)

Figure 4 CountryNet Driver's Console – satellite and terrestrial systems are integrated, with a simple interface

4.3 Satellite Call Techniques

Using a public carrier system inevitably raises concerns about access by unauthorised persons and authentication of calls.

In CountryNet the solution was to have a Closed User Group (CUG) for the railway and to have all calls initiated from the train controller. A train driver can make a call request using a short data message but all calls are made from the network. The Mobilesat short data message service has a guaranteed delivery time (unlike cellular telephone Short Message Services).

4.4 Demonstrated Performance

CountryNet has now been in use for over ten years. It has proven generally reliable, with availability of the order of 99.9%. The majority of the outages are on the terrestrial component, where leased analogue links have frequent failures and long outage times. The satellite sub-system has much better availability

Voice train orders (movement authorities) are carried on CountryNet and are supplemented by a GPS watch-dog. The watch-dog compares the train location (from the GPS reports) with the train order limits and raises an alarm if the train is likely to exceed the limits of its authority.

5 PACIFIC NATIONAL – GSM & SATELLITE

5.1 The Chameleon Locomotive

Until Pacific National commenced operation, all rail traffic was restricted to state government railways. Each railway had its own communications system.

Pacific National "NR" class locomotives are equipped with a suite of radio communication equipment to permit operation throughout the country. A computer and GPS receiver control the selection of radio equipment so that the locomotive uses the appropriate radio system for the particular area.

For operator traffic Pacific National built a system that used public carrier networks. The locomotives are equipped with GSM and satellite telephones, which connect through the Communications Control Centre for voice and data traffic. This approach avoided installation of proprietary hardware for the Victorian ASW system in an otherwise "clean cab".

Figure 5 : Pacific National NR Class locomotive with "chameleon" communications - right hand screen.

5.2 The Communications Control Centre

The Pacific National Communications Control Centre is a set of computer equipment that manages calls to and from locomotives. All locomotive public switched network traffic is routed through the Communications Control Centre so that a single set of radio equipment can be used for both train control and railway operations traffic. The Communications Control Centre maintains a list of all locomotives, the equipment on the locomotives and their drivers. This information is collated from regular messages from the locomotive, the crewing database and other databases.

This may all seem cumbersome but it has definite advantages. Some of the features of the Communications Control Centre are:

- Non-operational calls may be interrupted (pre-empted) if the satellite or GSM telephone is required for operational traffic. This is not available in public networks.
- Broadcast calls can be delivered to a number of locomotives over the GSM and satellite networks. An automated dialling process achieves this, with variable length buffers accommodating connection delays. The delivery of the broadcast to each locomotive is logged.
- Emergency calls from locomotives are forwarded to both the track controller and Pacific National. The Pacific National controllers are aware of the location of the train immediately an incident occurs.
- Locomotives are assigned in-dial PABX numbers within the Pacific National network. The in-dial number is routed through the Communications Control Centre, which redirects it to either the GSM or satellite telephone service, depending on the location of the locomotive. The person (or system) calling the locomotive does not need to know anything about the equipment on the locomotive or its location.
- Locomotive position data is collected regularly and is maintained at the Communications Control Centre as well as being available to the Pacific National supervisors. This information has proved valuable In a number of incidents.

The Communications Control Centre transforms the public network into a virtual private network with enhanced functionality.

6 TARCOOLA – DARWIN: SATELLITE ONLY

6.1 Background

The Tarcoola to Darwin railway has recently been completed (2004). This railway traverses the continent from south to north, terminating at the city and seaport of Darwin. (See Figure 2). The railway line between Tarcoola and Alice Springs has existed for many years, although it was rebuilt on a new alignment in the 1960's. A private microwave link system was built along the line to Alice Springs and spare channels on this system were leased to the public carrier. Mobile communications were by two-way radio, using an open channel system.

The extension to Darwin was built in a different commercial environment and with different technologies available. The low traffic on the line (typically one train per day) and the length of track (2,550 km) meant that a private microwave or fibre optic system was not affordable. There is little or no cellular telephone coverage over the majority of the route so satellite telephony was the obvious choice.

6.2 Risk Analysis

If the Darwin railway line had been completely new, satellite-only operation would have been a foregone conclusion. However, the portion from Tarcoola to Alice Springs previously had mobile radio so the satellite approach had to be proven to be no less safe. The principles of risk and hazard analysis set out in AS 4292[4] were applied. This analysis quantifies parameters that are inherently subjective and provides an objective assessment of the magnitude and severity of risk and its impact.

A number of scenarios were considered in the risk assessment, including:

- collision/incident with a train or track vehicle
- collision with car, livestock or pedestrian
- track failure due to flooding or heat buckling
- driver illness, passenger illness
- train failure (air hose, load shift, brake failure)
- dangerous goods spill.

The impact of an equipment or network failure concurrent with the incident was assessed. In each scenario a solution was identified. Solutions considered included:

- different satellite technology for the on-train and portable equipment (eg, one geostationary and one low earth orbit)
- Emergency Position Indicating Radio Beacons (EPIRB) issued to the crew, locomotive and track maintenance personnel
- regular GPS position reports so that the last reported position of the train is within a reasonable search area
- dedicated emergency phone lines and numbers at train control with multiple line access
- open channel portable radios for local area communication (for roll-by inspections).

In a metro system emergency call response times of less than a few seconds are usually mandatory. Here, the emergency call connection time is less important than the certainty that connection will be made. It will take many hours for assistance to arrive at the site, even by air, so an accurate train location is more important than an immediate alarm.

7 QUALITY OF SERVICE

7.1 The Differentiators

Railways have always defined train radio systems for a particular grade of service. They have then ensured that the grade of service is maintained. This is relatively straightforward.

When public services are used there is a completely different situation. Rather than being the sole or dominant user, the railway now generates a tiny proportion of the system revenue and is not of particular commercial importance to the system owner. No longer can the railway demand a quality of service. The railway must assess whether the service offered is acceptable and must then make its own assessment of whether the quality of service is being maintained.

In an analogue mobile radio system and many digital systems, the quality of the service can be assessed largely by measuring the received signal strength at the mobile. If the mobile has sufficient signal, the required quality of service will probably be obtained. This is a necessary but not a sufficient condition for public carrier networks.

7.1.1 Factors affecting public networks

Public networks are designed for maximum profitability. The operator certainly wants to provide coverage and to handle calls – but at the best return on investment. The network layout is not necessarily stable and will be reconfigured to improve return. Coverage of a low revenue area or sector will be sacrificed, if necessary, to provide improved capacity in an area with greater demand. This can have serious consequences for the railway as its requirements are focused on a defined route.

7.1.2 Drive testing[5]

Cellular service providers perform “drive testing” to optimise their networks. The traditional drive test tool uses a phone (connected to a computer) to re-create the problems that a subscriber may experience.

A drive test should be able to duplicate the problem if a subscriber’s call is dropped while operating in a moving vehicle in a particular location. Drive testing also identifies blocked calls (access failures), poor voice quality, and lack of significant coverage.

7.1.3 Sources of network problems

There are a number of causes for blocked calls, dropped calls, and poor voice quality. These can include: poor radio coverage and, in CDMA: pilot pollution, missing neighbour base stations, search window setting problems and timing errors. There are also causes not related to radio parameters, such as those associated with cell site capacity, backhaul capacity, or call processing software.

Lack of radio coverage is often the cause of dropped calls and blocked calls. This may occur due to a localized coverage hole (such as a low spot in the road), or it could be due to poor coverage at the extreme edge of the coverage area.

Pilot pollution is the presence of too many CDMA pilot signals. The additional pilots act like interference to the subscriber's call. The missing neighbour condition occurs when the phone receives a high-level pilot signal and it does not appear in the phone's neighbour list. It acts as an interfering signal and can cause dropped calls and poor quality. If radio's base station search window is not set properly the phone cannot find neighbouring base stations and calls will drop out as the mobile moves.

7.1.4 Quality of service measurement

Cellular service providers measure the quality of service though drive tests, as discussed earlier. The results are not usually available to a railway in any useful form. If a railway wants to know the quality of service, it must make its own measurements.

Some regulatory authorities measure quality of service. One authority that publishes their requirements and the results achieved by the carriers is the Infocomm Development Authority of Singapore (IDA). IDA surveys the service quality the mobile service providers for the GSM900, GSM1800 and CDMA mobile networks.

Some Quality of Service parameters that are applicable to all networks are set out in Table 1. These are the parameters used by IDA.

Parameter	Description	Criterion
Call Success Rate	The number of successful calls established over the total number of mobile call attempts.	A call is successful when a network connection is established.
Service Coverage	The network's ability to achieve at least the specified signal strength during the mobile call holding period.	Samples of signal strength are taken at half-second intervals. The call is held for 100 seconds.
Voice Quality	The voice quality measured with the Mean Opinion Score.	The lowest acceptable score is "2" on the rating scale.
Call Drop-out	Unintended disconnection of mobile calls by the network.	Network disconnection during the 100-second holding period.

Table 1 : Quality of Service Parameters

Voice Quality

Voice quality and the signal strength are equally important in determining the quality of cellular transmission. (Voice quality is also a key parameter in voice-over-internet systems.)

To measure voice quality, the IDA injects a phonetically balanced speech sample into the network and compares a digital copy of the original with a copy received after passing through the network. The quality is then rated according to its level of distortion. This process is a variation on the international standard technique for voice quality measurement.

7.1.5 Railway application

One argument for using public networks for train operations in Australia is that some communication is better than none. This is certainly true, provided that there is not a false sense of security. If the operators expect communication, they will rely on it. Accident investigations provide many instances of assumptions about communication reliability or unreliability having tragic consequences[6].

Any system or service being used for railway operations should be tested and audited regularly. This applies to both private and public networks.

8 OFF-TRAIN COMMUNICATION

The CountryNet system was the first to use a "repeater mode" for off-train communication. A mobile radio transceiver on the locomotive communicates with the portable radio, while the satellite telephone or other radio on the train links to control. The radio systems are cross-connected so the locomotive radio operates as a 'repeater".

This arrangement substantially improves the reliability of communication when the driver is outside the locomotive cab. If several technologies are in use (eg cellular, satellite and private mobile radio) it reduces the number of portable radio devices required to just one.

Portable radios have limited coverage due to the height of the antenna, shielding by the user's body and the train and the lesser performance of the portable radio. The limited battery capacity of the radio and constraints on electromagnetic radiation close to the user substantially limit its output.

In addition, the train and its load attenuate the radio signal when the driver is walking along the side of the train or is at the rear of the train. A high locomotive antenna with good performance compensates for some of these losses.

The antenna for the locomotive radio is mounted on the cab roof and has good coverage along the train. Being (typically) 4.5 metres above rail and 5 metres above the ground beside the track, there is considerable "height gain" for the locomotive antenna.

Figure 6 : A location where off-train communication is difficult. The terrain will limit coverage to the rear of a train on this curve.

The signal can be further attenuated by terrain between the locomotive and the rear of the train (Figure 6). A prudent operator will identify any areas where coverage might be lost and implement procedures or other solutions for these areas.

This method of off-train communication has proved very successful and is now employed on most Australian railways.

9 CONCLUSION

There are viable public network services for low traffic railways. For many Australian railways a public carrier service is the only affordable option.

The technologies available include GSM and CDMA cellular telephony, geostationary satellite telephony and low earth orbit satellite systems.

These technologies all conform to international standards for at least some of their interfaces. The most standardised is GSM, followed by CDMA and then to a much lesser extent, the proprietary satellite systems. Each technology has its own peculiarities with both benefits and disadvantages.

While none of the technologies provides the set of features normally accepted for railway applications, they may each be incorporated into systems that achieve what is required.

Low traffic line operations are not usually concerned with the immediacy of call connection. They are usually a long way from any emergency response teams. Reliable connection of an emergency call and automatic position reporting are more important than the speed of connection.

A connection time of thirty seconds may be unacceptable in a metro environment but, accompanied by a position report, it is most acceptable in a remote location. Reliable connection may be achieved by using multiple public carrier services (or technologies) for important traffic.

Special consideration should always be given to communication for train crews that have to leave the cab and work at the side or rear of the train.

A prudent operator will ensure that the coverage of public carrier systems is known and understood by train crews. Gaps in coverage may be solved by additional technology, by procedures or by negotiation with the carriers.

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[1] Australasian Railway Association, *Railway Communications Strategic Framework*, June 2004.
[2] TJ Deveney, "Alternative Safe Working System", IRSE Technical Meeting, Moama, November 1990.

[3] Call prioritisation is unavailable to users of the CDMA and GSM networks in Australia.

[4] Australian Standard AS 4292, *"Railway Safety Management",* Standards Australia.

[5] Agilent Technologies Application Note 1345, "*Optimising your CDMA wireless network today and tomorrow using drive-test solutions"*.

[6] JJ Aitken, "*You can get lonely out there*!" Conference On Railway Engineering, Darwin 20-23 June 2004