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Minnesota Department of Public Safety

Division of Emergency Communication Networks

Performance Review:
ARMER Radio System at I-35W Bridge Collapse

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Public Safety Consulting, GIS, and Software
www.geo-comm.com

Main: 320.240.0040 Fax: 320.240.2389 Toll-free: 888.436.2666
601 West St. Germain Street St. Cloud, MN 56301

EXECUTIVE SUMMARY

Beginning in the late 1980s a concerted effort was made in the Minneapolis/St. Paul Metropolitan area by local government public safety communications professionals to implement an integrated two-way radio system that could support the day-to-day activities of city, county, special district and state government, while also providing robust communications interoperability capabilities necessary for effective response and management of complex emergency incidents.1

As a result of these early efforts a shared region-wide, two-way radio infrastructure was in place for virtually all state and local public safety agencies in the Twin Cities Metro area at 6:01p.m. on August 1, 2007, when the Interstate 35W bridge over the Mississippi River in Minneapolis collapsed, killing 13 and injuring hundreds. Now part of a statewide initiative, the radio system is called the Allied Radio Matrix for Emergency Response (ARMER), and under the guidance of a Statewide Radio Board (SRB) composed of state and local participants, the ARMER system is being constructed statewide to serve state government agencies, as well as city, county, and special district agencies that choose to operate on the system.

The purpose of this report is to assess the performance of the ARMER system during the response to the bridge collapse on August 1, 2007, and to determine the lessons learned so that they may be applied to the statewide build-out and to other public safety communication systems developed elsewhere.

During the peak hour of activity surrounding the initial response and rescue efforts (7-8p.m. on Wednesday, August 1) over 16,000 radios were turned on and linked to the ARMER system in the Twin Cities area. These radios accessed the ARMER system over 27,000 times and utilized over 2,500 minutes of radio airtime. These figures represent more than twice as much activity on the system as the hour immediately preceding the bridge collapse.

This report evaluates the system's performance in three major categories and via three approaches. The categories make up the "Three Cs of Effective Radio Communications Systems":

- Capacity of the system to carry peak radio traffic
- Coverage of the radio system's signals to and from affected areas
- Clarity of the radio system's voice messages – their ability to be well heard and understood

[1] The reader is referred to Appendix A for a more complete historical context of the development of and improvements to public safety and local government two-way radio in Minnesota, as well as Appendix C for a listing of common communications system acronyms and definitions for a more complete understanding of the terms used in this report, as well as Appendix D for a "primer" on what trunked radio is and how it works.

The approaches taken in the study were:

- To analyze the empirical data collected by the ARMER system's central control computers relating to activity and locations.
- To survey responders or communication personnel for their input and perceptions concerning the performance of the ARMER system.
- To conduct three structured 'focus group' sessions involving:
  - Major agency scene commanders (law enforcement, state patrol, fire, EMS)
  - Major agency incident dispatchers (Minnesota State Patrol, Minneapolis, Hennepin County Sheriff and EMS)
  - System technologists and administrators from Mn/DOT, Hennepin County, Minneapolis, and the Metropolitan Emergency Services Board
- To complete one-on-one interviews with bridge collapse incident and communications managers.

The emergency responders and dispatchers operating on the ARMER system who responded to the survey reported:

- 96 percent felt the ARMER system performed well during the incident
- 95 percent felt the digital audio clarity (including signal coverage) of ARMER was good
- 83 percent said ARMER provided them with appropriate capacity access for their needs
- 12 percent said that their training in how to use the ARMER system was inadequate

Participants in the focus group agreed:

- "Without the ARMER this incident would have been a catastrophe"
- "We have removed communications as an element of failure in disasters. Now we can only blame our use of the system, not the technology"

One of the lessons learned from this incident was that talk-group based access priority and how those priorities are applied to talk-groups had an impact on system performance and the perceptions of system capacity as perceived by users of the system. Further, the arrangement and use of "talk-groups" and the priority assigned to those talk-groups was the single most important element affecting system performance during the I-35W incident.

Lessons were also learned about how other, distant ARMER users who monitored the incident's radio traffic from miles away impacted ARMER system availability in their jurisdictions, which were many miles from the scene of the bridge collapse.

Lessons were learned about the importance of consistent training for dispatchers, scene commanders, and agency system administrators who make advance decisions regarding access priorities and talk-group selection. From this perspective, there was a much greater understanding of the impact of various access priorities on the talk-groups and of the impact of other access pathways such as "private call" and telephone inter-connect two-way radio capabilities.

To the credit of those early planners and advocates, the partnerships and years spent developing and implementing a shared infrastructure produced a true sense of shared ownership that can serve as a model for others. It is a model of sharing among disparate public safety disciplines and agencies that does not come natural, and requires a continuous commitment to shared goals. It may not be often that persons representing organizations such as transit, public works, highway maintenance, public safety, news media, EMS, the military, and other federal organizations need to work together at a major disaster scene, but, when the need arises the public is well served by the shared development of the tools and practices needed to coordinate the activities of all responders and involved agencies.

It was also apparent that the overall effectiveness of the ARMER system in supporting this tragic incident was the fact that ARMER is not a special radio system to be taken out of storage and used during special events. Rather, the ARMER system is the radio system used by responders in their day-to-day operations. There was no need for special ad-hoc training or for special technicians to rush to the scene to activate special devices to facilitate inter-agency communications. The scalable ability of the ARMER system allows it to grow with any size incident to address the communications needs. Those resources are built into ARMER system waiting for just such an incident.

Finally, there is no question that the resources of the ARMER system were heavily taxed during this incident. There were instances where users encountered excessive delays in obtaining access to the system. However, many of these delays were found to be the result of:

- Inappropriate talk-group selections by the users or persons directing them
- Inappropriate assignment of access priorities to some talk-groups at their inception
- Inappropriate "patching" of two or more talk-groups together
- Excessive talking by some of the users
- Inadequate channel capacity at some ARMER tower sites (in the context of these four issues)
    - Meaning: Had the above four issues not been operative, there may have been adequate channels.
- Too much monitoring of bridge collapse scene radio traffic from locations miles away from the bridge collapse scene.

Public safety communications professionals have significant experience with network traffic capacity in the United States with the Enhanced 9-1-1 (E9-1-1) system. E9-1-1 systems have existed since the late 1970s and they are dependent on a large number of users (wired and wireless telephone subscribers) having access to a limited number of trunked telephone circuits to carry emergency telephone calls to Public Safety Answering Points (9-1-1 dispatch centers). These networks are engineered to a “P.01” access level, which means that only one call out of every 100 9-1-1 calls can encounter a busy signal when dialing 9-1-1 during the busy hour of the busy day. And, when a busy signal is encountered, the probability of encountering a busy signal again on the second attempt is virtually non-existent.

During the response to the I-35W bridge collapse on August 1, 2007, the ARMER system provided access to users far better than a “P.01” grade of service. Whereas cell phones and their related “Push to Talk” walkie-talkie like services frequently used by the public and public safety officials for routine communication were often unavailable at the disaster scene (due to commercial system overloads), the ARMER system provided consistent and reliable communications along multiple paths (talk-groups) throughout the incident.

In the final analysis, the ARMER system performed admirably throughout the response and well within its programmed priority parameters. It provided strong, high quality audio to thousands of users in thousands of radio transmissions, thereby knitting the entire response community together into one functional unit. Few, if any, technology systems are built to provide unfettered access, regardless of demand. There are no telephone systems that can handle unlimited demand for simultaneous dial tone, no Web sites or internet pathways that can handle everyone going to the same Web site at one time, and no elevator systems can transport everyone from the top floor to the main floor instantly.

Introduction

GeoComm was retained by the Minnesota Department of Public Safety, Division of Emergency Communication Networks (DPS/ECN) to conduct a detailed assessment of the performance of the Allied Radio Matrix for Emergency Response (ARMER) 800 Megahertz (MHz) trunked radio system during and after the collapse of the Interstate 35W bridge over the Mississippi River in Minneapolis on the evening of August 1, 2007.

This incident represented one of the most communications intensive emergency incidents to occur in the state of Minnesota and, other than September 11, 2001, in New York City, one of the largest ever in the United States. It involved emergency response from over 170 agencies and a massive initial response from units of the following agencies:

- Hennepin County Medical Center Ambulance Service (HCMC/EMS)
- Hennepin County Sheriff's Office (HCSO)
- Minneapolis Fire Department (MFD)
- Minneapolis Park Police Department (MPPD)
- Minneapolis Police Department (MPD)
- Minnesota Department of Natural Resources (Mn/DNR)
- Minnesota Department of Transportation (Mn/DOT)
- Minnesota State Patrol (MSP)
- North Memorial Medical Center Ambulance Service (NMMC/EMS)
- University of Minnesota Police Department (UMPD)

The responses from numerous other local, state, and federal agencies required communications support for several weeks following the bridge collapse as the rescue, recovery, and investigation phases of the collapse unfolded.

This took place in an environment where units of city, county, regional, special purpose jurisdictions (transit, university, airport, etc.), and state government had worked for nearly two decades to envision, plan, and fund the most comprehensive, integrated, shared governance structured two-way radio communications system in the nation.

From its inception, this radio system was intended to be the regular, daily usage two-way radio system over which literally "everything with a tax exempt license plate", including all public safety, public works, highway maintenance, public transit, and emergency management radio users would use a single integrated communication system; a system that could support the coordination of multiple agencies and organize the activities of responding agencies when a major incident occurred. It was the goal of the system's planners to eliminate the days when responders were obliged to carry multiple radios in order to communicate with each other and the days when inadequate signal coverage or talk capacity would hamper their ability to effectively manage any significant incident.

Achieving this goal would require a commitment by government entities at all levels, a major local and state (and, eventually, federal) funding commitment, as well as extensive involvement by end users in the system design, system planning, operational rule making, training, and in the ultimate implementation. As of this writing, there is nearly full participation by all local, regional, and state governments in the Minneapolis/St. Paul Metro area on the ARMER system. There has been a consistent phased migration of user agencies in the Twin Cities Metro area over the past ten years. While the ARMER system technology is commonly referred to as a "P25 compliant", digital, simulcast 800 MHz trunked radio system, the basic technology has undergone many refinements and upgrades since its initial design and acquisition in the late 1990s. It fully supports subscriber radios from several vendors and provides service to well over 20,000 subscribed portable and mobile radios in the Twin Cities Metro area alone.

The purpose of this study is to examine how the ARMER system performed and how it met the needs of the emergency responders. The examination is from both a detailed technical analysis of the system electronics as well as from the perspective of ground level field users of the system.

Methodology Employed in this Analysis

The analysis effort in this report consisted of five major components:

- Development and administration of a controlled access, Web-based survey intended for line level working dispatchers and field responders to share their perceptions of the performance of the radio system from several different aspects.
- One-on-one interviews with the ARMER system's main technologists and the collapse incident managers from Mn/DOT, Minnesota State Patrol, Hennepin County, and the City of Minneapolis (all system owners), and the receipt of volumes of data representing metrics captured by their central processors dealing with system usage and performance.
- Three videotaped "Focus Groups" designed to elicit candid commentary from three groups of system users and technicians, as follows:
    - Public safety first responders to the bridge collapse incident representing law enforcement, fire, and EMS.
    - The public safety dispatch personnel who managed communications during the bridge collapse incident.

- System technicians and technologists who manage and maintain the radio system on a daily basis, several of which were also involved in monitoring and tracking system performance on the night of the collapse.

- Detailed analysis of survey results, collected data on system metrics, and user commentary.

A Word about Our Reader Audiences

Because readers of this report will come from a variety of perspectives and levels of technical expertise, this study is designed to offer the technical and historical context of why the Twin Cities Metro public safety community found it desirable and necessary to move towards the implementation of a common radio communication infrastructure shared by state, regional, and local governments, and how the ARMER system has expanded and will be expanded over the next few years to serve the needs of the entire State of Minnesota.

ARMER System History

Early planners in the Twin Cities Metro area began to discuss and propose the implementation of a regional, 800 MHz trunked radio system that would be capable of serving all public safety, public service, public transit, and general state and local government two-way radio needs in the entire nine county Metro area.

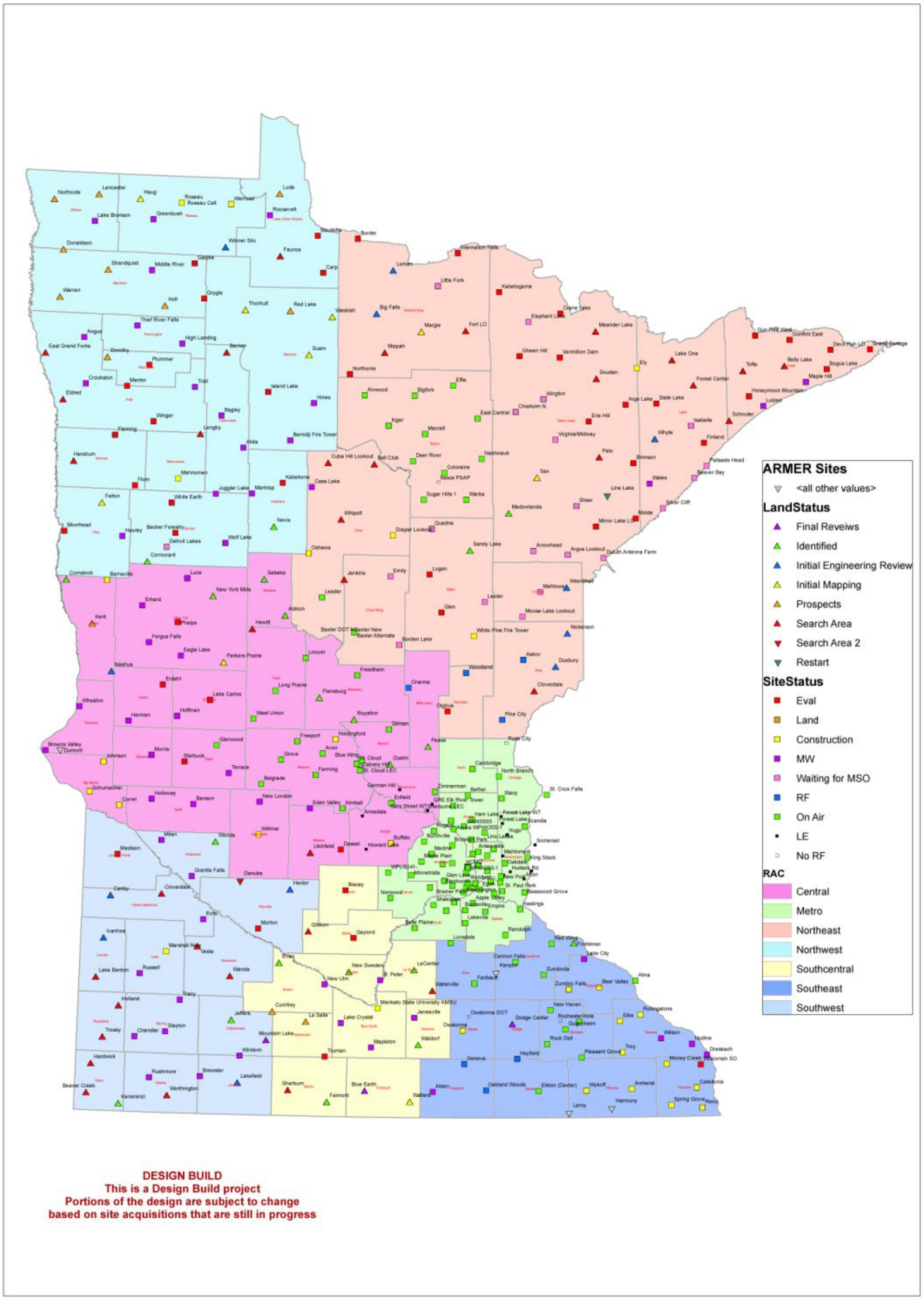
The original regional 800 MHz system went through a decade of debate, governance organizing, planning, design, acquisition, and implementation before the first agencies began to use it on a daily basis. The first use of the Metro area system began in 2002 by the entire City of Minneapolis, all Hennepin County government, the Metro operations of the Minnesota State Patrol and Mn/DOT, Metro Transit, all Carver County government, and several suburban agencies in Hennepin County. Since that time, all remaining Hennepin County agencies, and all Anoka, Dakota, and Ramsey County agencies have migrated to the system.

In 2001 a plan was developed to extend the Metro system into a statewide system. The original plan called for six phases; Phase One was the initial Metro area backbone. Phase Two was local enhancements to the Metro area backbone and Phases Three through Six provided for the extension of the backbone into greater Minnesota. With the expansion of the regional system outside of the Metro area it was given a name to befit its statewide character as well as its shared ownership and governance structure: ARMER, which stands for Allied Radio Matrix for Emergency Response.

Since its inception ARMER has been scaled up to serve as the backbone for Minnesota's statewide shared system, supporting all two-way radio communications activities of all state agencies, as well as those of any public safety agency which chooses to participate in the system.

In 2005, the Minnesota legislature provided funding for the continued implementation of the ARMER backbone into 23 counties of central and southeastern Minnesota. That implementation is currently underway and will be substantially completed in spring 2009. Implementation in the remaining 55 counties of the state was authorized in 2007 and the Minnesota Department of Transportation (Mn/DOT) has completed the detail design and began initial implementation in July 2008.

ARMER SITES



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The above map shows the planned location of each of the over 300 towers that will make up the ARMER system upon completion. The ARMER system is being developed and will be operated by the Minnesota Department of Transportation. As developer and operator, Mn/DOT is in various stages of site development throughout Phases Three through Six. This includes everything from land acquisition, construction of towers, to installing microwave and radio equipment on the towers. The ARMER program anticipates that the basic backbone, with 75 percent statewide coverage, will be in place across the state in 2010. The ARMER program has set the goal of having the backbone built to a 95 percent county-by-county mobile standard (this means that ARMER will serve a mobile radio effectively in a minimum of 95 percent of the land area of each of the state's 87 counties) by the end of 2012. This is in advance of the Federal Communications Commission (FCC) mandated narrowbanding deadline of 2013, which is a requirement that will cause numerous local governments to replace non-compliant wideband VHF and UHF radio equipment. Additional details of the ARMER plan, including technical and operating standards, are available on the Statewide Radio Board Web site as www.srb.state.mn.us.

With final funding being passed by the legislature in the 2007 session and the ARMER program having completed the studies required by that legislation, Phases Four, Five, and Six have been rolled in to one final phase now called "Phase 456". In Phase 456, Itasca County will join the system in early 2009. All other Phase 456 counties (46 in all) have partnered with the ARMER program and are in the process of completing county-specific studies. These studies will assist the emergency responders and county boards in making a business decision based on the following three options:

- Upgrade (and make narrowband compliant) their current VHF analog system
- Build a new VHF digital system which would be narrowband compliant
- Transition to the ARMER system

In early 2009, all Metro area cities and counties will be operating on the ARMER system when Washington and Scott Counties complete their migration. Phase Three includes 23 counties in central and southeastern Minnesota. Olmsted and Stearns Counties, which include the Cities of Rochester and St. Cloud, have already fully transitioned to the ARMER system. In the southeast, Goodhue, Wabasha, and Winona Counties are in the process of migrating to ARMER, and in central Minnesota Sherburne, Wright, Kandiyohi, Meeker, Benton, Grant, and Douglas Counties are in the process of transitioning to ARMER. The balance of the Phase Three counties are in the process of studying their radio communication options and have yet to make a business decision related to their radio communications future.

While most other states and entities trying to replicate ARMER's functionality have relied heavily on federal influence and funding to move their processes along, in Minnesota the implementation was initiated long before the well documented communications problems of September 11 in New York City, with no federal encouragement or funding whatsoever. Certainly, the availability of federal funding incentives geared toward encouraging implementation of such systems have allowed the State of Minnesota and local agencies to take significant advantage of federal funds to accelerate the already envisioned implementation and growth of ARMER.

ARMER System and Technology

The basic ARMER infrastructure uses the Motorola® Smart Zone™ technology in a 700/800 Megahertz (MHz) digital trunked radio communication system rooted in the non-proprietary APCO P25 architecture. Upon full deployment the ARMER system will consist of:

- A statewide infrastructure of towers, microwave, and radio frequency (RF) equipment necessary to provide coverage and interoperability throughout the state
- P25, digital trunked 700/800 MHz system capable of meeting the needs of public safety agencies (city, county, state agency, NGA, and tribal) throughout the state
- State of the art equipment that is scalable and robust
- Equipment capable of linking legacy systems together through regional and statewide talk-groups (a "system of systems" approach)

The ARMER system is a digital trunked radio system. Simply put, it is a computer controlled radio system that takes a number of radio channels (up to dozens) and sets them aside to be allocated on an instantaneous, as-needed basis to field radios to support their communications needs. The field radios (also called subscriber radios) are all in constant contact with the trunked system's main control center via a control channel and it is via this control channel that any given radio is instructed by the main control center to internally switch to a specific radio frequency to hear some upcoming communication on a talk-group which that field radio user has selected, or is scanning. It is also due to this constant contact between the main control center and the field radio that the field radio can always know whether or not it is in range of the radio system. The advantages of trunking technology are several, but four of the more critical ones are:

- Far greater efficiency in the use of scarce radio channels.
  - Many experts say that the usage efficiency of trunked radio channels can be ten times or more than that of radio channels used in non-trunked systems.
- Far greater capacity for several distinct talk-paths to carry communications than with a conventional channel-based system. On a trunked system these are called talk-groups.
  - It is not unusual for a 20 frequency trunked radio system to support 100 or more talk-groups, while the same 20 channels used in a conventional (non-trunked) radio system could only support 20 similar usage talk-paths at any instant.
- A user always knows whether their radio is within range of the trunked system.
  - This can be of great comfort to public safety personnel upon entering indoor or outdoor high risk areas.
- Only one user is electronically permitted on any one talk-group at any one instant.
  - This means the system does not allow user transmissions to fully or partially blank another user transmission occurring at the same time.

Over and above the basic technology of trunked radio, such systems are also often configured to employ digital modulation and/or simulcast technologies, although neither of these technologies is unique to trunked radio. A digital modulation system is one in which the radio signals passing to and from the radios contain not analog wave forms (lines that look like squiggly waves on a radar screen type oscilloscope) but packets of 1's and 0's, also known as digital bits. If enough digital bits make it from the transmitter to a receiver (about 97.5 percent of them) then the bit error rate is low (good) enough that the digital receiver can reconstitute the digital bits it receives back into an analog form that can be sent out the loudspeaker as a near perfect recreation of the original sound.

A simulcast system is actually a simultaneous broadcast system in which the same radio transmission is broadcast from two or more radio towers simultaneously, so as to increase the net effective penetrating power of each transmission, thereby increasing the chances that it will be heard by field radios.

At its core and of critical importance, the ARMER system is intended to not only meet the day-to-day demands of the several tens of thousands of subscriber radio users it can support, but it is also intended to provide a mechanism for the effective coordination and inter-operation of those radio users from a variety of disciplines and jurisdictions during a major public safety incident such as the August 1, 2007, bridge collapse. This concept of using one's everyday radio for routine as well as major interagency emergency communications has proven very valuable and means that the appropriate radio equipment is always at hand, and it's the same radio equipment on which one was already trained.

The ARMER System as Implemented in the Twin City Metro Area

The ARMER backbone as implemented in the Twin Cities is composed of a large regional "umbrella" subsystem and two local subsystems that are integrated to operate as one.

The regional subsystem consisting of a number of towers throughout the nine county Twin City Metro area linked together by a redundant, dual-path microwave and fiber-optic system. (Note: The southern microwave loop of the ARMER system was inoperable on August 1 as some of the equipment was being relocated to accommodate Dakota County's transition on to the ARMER system. A second redundant pathway -- a critical fiber-optic link -- was actually carried under the collapsed bridge and was severed at the time of the collapse, but due to its alternate routing configuration, another fiber link -- a third level of redundancy -- the link destroyed in the collapse presented no communications problems.)

This Metro area regional subsystem is designed to provide adequate signal coverage (defined as a strong enough digital radio signal in any given place to provide adequate service to/from a portable radio on the street, out of doors in the nine county Metro area) and service capacity (defined as the ability to provide an adequate number of channels to support the expected channel/talk-group demand during periods of peak activity) to "regional users," defined as state agencies (Minnesota State Patrol, Mn/DOT, Metro Transit, etc.) and the regional EMS service providers.

The other two subsystems relevant to this report consist of several tower/transmitter sites (some shared with the regional system) to provide increased capacity and increased coverage:

- The Hennepin County subsystem which was constructed in 2001 when the regional backbone was constructed.
- The City of Minneapolis subsystem which was also constructed in 2001 when the regional backbone was constructed.

All three subsystems are linked together and controlled by the ARMER system's main redundant control computers so as to act as one large system.

As a result of this common control, the following additional attributes of the ARMER system are programmed into radios operating on the system:

- Individual agency radios are "homed on" one of the systems, such as a City of Minneapolis radio is programmed to operate within the coverage area of the Minneapolis subsystem it prefers and seeks out service from a Minneapolis site and a Minneapolis channel, while a sheriff's office radio (for example) subscribed to the Hennepin subsystem prefers and seeks out service from a Hennepin site and channel.
- Where an individual radio is operated in an area where it cannot get signal from its preferred subsystem or the preferred subsystem is busy, it will seek to roam to another system (if one is present) where it can get service.
- Where an individual radio is operating on a talk-group that is not programmed in that radio to prefer a given system, the radio will seek the best signal from any available tower that will provide access to that talk-group. This is frequently the case for state agency and regional talk-groups on radios such as the Minnesota State Patrol, which roam far and wide on the system.

For example: If a Minneapolis subsystem radio is operated in the far corner of Carver County (25 miles out of Minneapolis) on a Minneapolis usage talk-group, it would seek a Minneapolis subsystem site, but probably not be able to reach one. If the talk-group selected on that radio had been authorized for wide area usage (but most are not), it might then look for a Hennepin subsystem site (serving the Carver County area) to access the system, but would probably not be able to find one in Carver County. Ultimately, this Minneapolis subsystem radio would look for a regional backbone site, and if it found one, it could roam over to the regional site to obtain service.

With this understanding, it is important to point out that, from a radio system performance perspective, the bridge collapse occurred in almost the ideal location. Not only was it generally located near the center of the Twin Cities Metro area, it was also located in a spot from which radios subscribed to all three subsystems could access resources of each subsystem, thereby providing maximum capacity at the bridge's location.

What Does "Maximum Capacity in the Bridge Location" Mean?

There are three transmitter sites with a total of 52 channels on 52 repeaters available near the bridge collapse site in downtown Minneapolis. However, because these channels are resident on three functionally separate subsystems (regional, Minneapolis, and Hennepin) it means that only about 30 concurrent communications pathways could be in use at one instant. The reason for this is (for example) that if three radios from three separate subsystems (state trooper on the regional system, Minneapolis police officer on the Minneapolis subsystem, and a Hennepin County Deputy Sheriff on the Hennepin subsystem) were all talking on the same talk-group they would be doing so over three separate subsystems, with each subsystem using a separate repeater to re-broadcast what it was hearing or transmitting on that one talk-group. Therefore, this one talk-path (that talk-group) would be using three channels in this area, due to the fact that this area is one of the very few areas served well by sites for all the subsystems.

The next page has a map of the Twin Cities Metro area, which depicts the relative location of the I-35W bridge.

On the following page the map are two diagrams that depict the general configuration of the systems. Note the varying number of channels available at the several sites within each of the color coded areas. The more channels available in a given area the greater the system's capacity to support concurrent communications pathways (talk-group usage) is in that area.


Locating the I-35W bridge site in
the context of the greater Twin Cities metro
Elk River
Dayton
Ramsey
Andover
Anoka
Champlin
Rogers
Fletcher
Oak Park
Coon Rapids
Lino Lakes
Circle Pines
Lexington
Forest Lake
Weston
Hugo
Maple Grove
Osseo
Spring Lake Park
Mounds View
North Oaks
White Bear Beach
Dellwood
Corcoran
Brooklyn Park
Fridley
Bald Eagle
Shoreview
Brooklyn Center
Arden Hills
Vadnais Heights
Bellaire
Mahtomedi
White Bear Lake
New Brighton
Hilltop
Columbia Heights
Hamel
New Hope
Crystal
Robbinsdale
Pine Springs
Little Canada
Saint Anthony
Maplewood
North Saint Paul
Plymouth
Golden Valley
Lauderdale
Roseville
Falcon Heights
Long Lake
Wayzata
Minneapolis
Oakdale
Landfall
Crystal Bay
Minnetonka Beach
Saint Louis Park
Saint Paul
Deephaven
Hopkins
Woodbury
Minnetonka
Lilydale
West Saint Paul
Excelsior
South Saint Paul
Edina
Richfield
Mendota
Mendota Heights
Sunfish Lake
Newport
Chanhassen
Eden Prairie
Inver Grove Heights
Bloomington
Saint Paul Park
Cottage Grove
Eagan
Shakopee
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Burnsville
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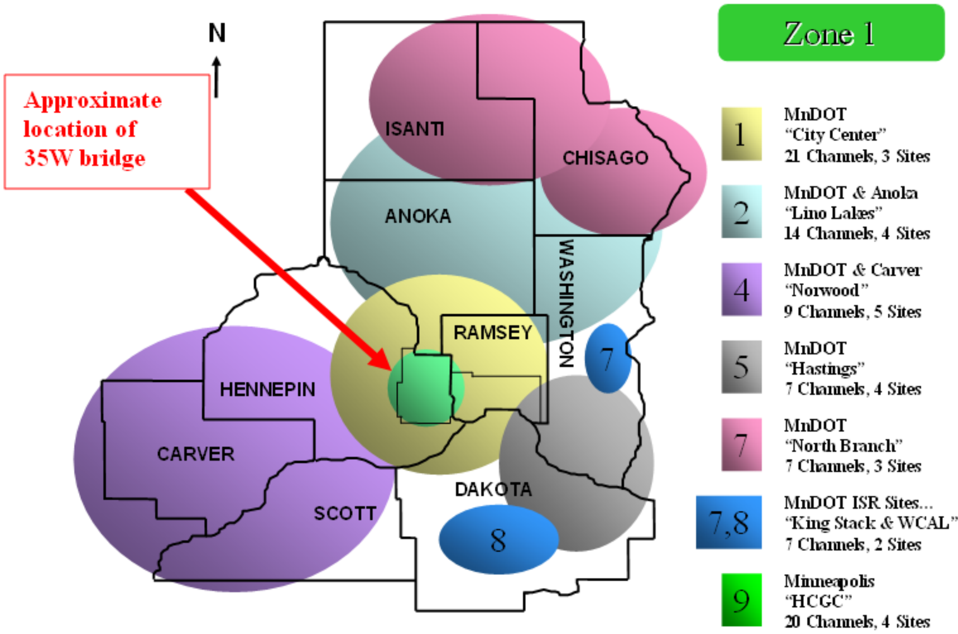
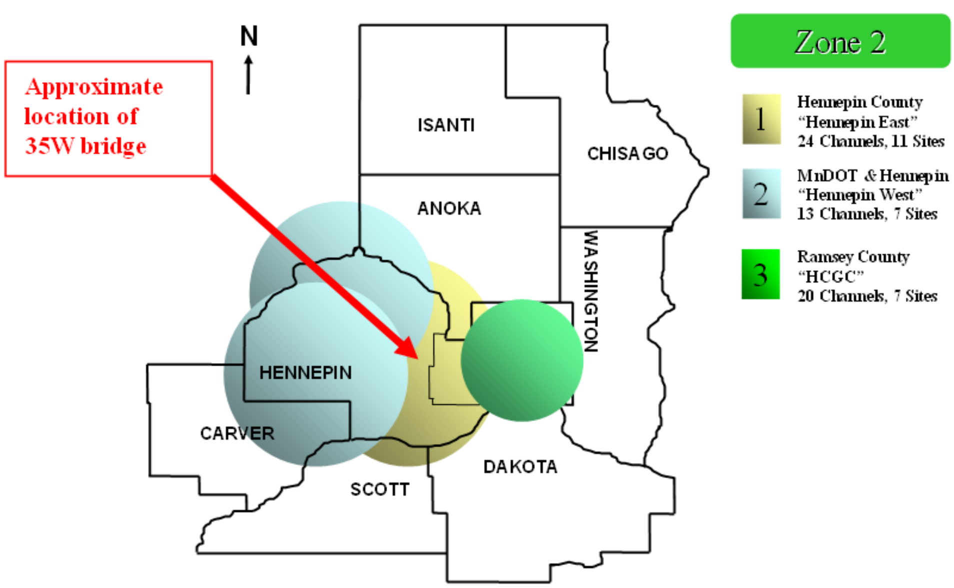
Zone 1 Site Locations



Zone 2 Site Locations



It is the purpose of this analysis to determine the degree to which the ARMER system, as implemented in the Twin Cities Metro area, met its design objectives and what lessons might be learned from its use and performance on that tragic summer evening and the several weeks thereafter.

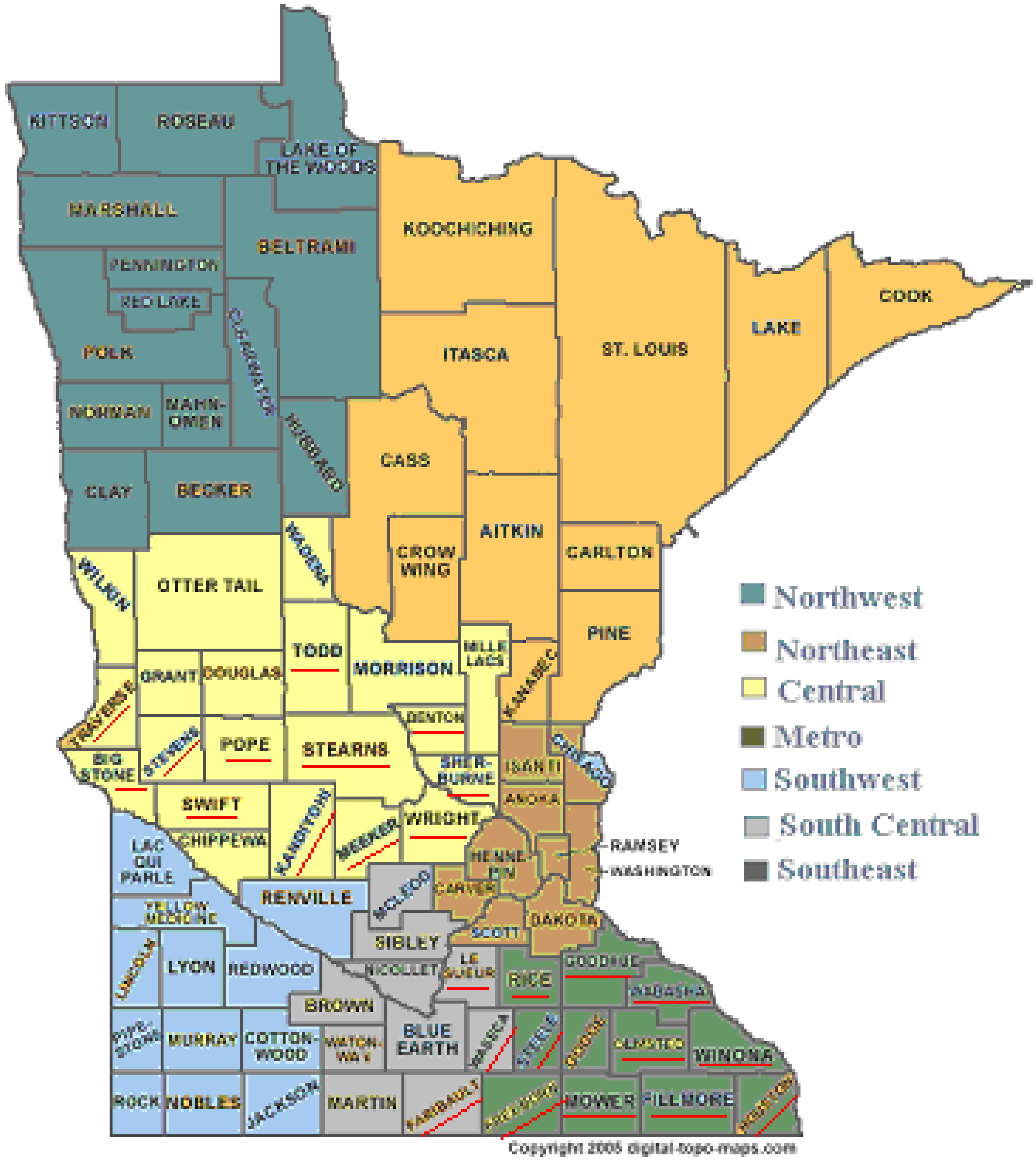
More importantly, the Statewide Radio Board and ECN want to fully understand the use and performance of the ARMER system so that as it is built out across Minnesota, and other public safety responders are trained to use the system, it is the most effective communications system and the training is as thorough and accurate as possible.

Governance

Upon the completion of the basic communication and interoperability backbone in the Twin Cities Metro area, the focus for the communication infrastructure shifted from a regional focus to a statewide focus. The 2004 legislature created the Statewide Radio Board (SRB). The SRB is multi-disciplined body composed of 21 members with 7 state members and 14 non-state members evenly divided between representatives from the Metropolitan area and greater Minnesota. The SRB establishes technical and operational standards of the ARMER backbone and monitors the implementation of the backbone throughout the state. The SRB has also been designated Minnesota's State Interoperability Executive Committee (SIEC) which administers and oversees Minnesota's Statewide Communication Interoperability Plan which includes technical and operational issues of public safety communication interoperability among all public safety entities.

The 2004 legislature also provided for the creation of Regional Advisory Committees and Regional Radio Boards (RAC and RRB) to determine and administer regional enhancements and to facilitate local and regional planning for integration onto the ARMER system. The RRB's also play a key role in the broader discussion of public safety interoperability among all public safety agencies (local, state, tribal, and federal) and with our neighboring states and Canada.

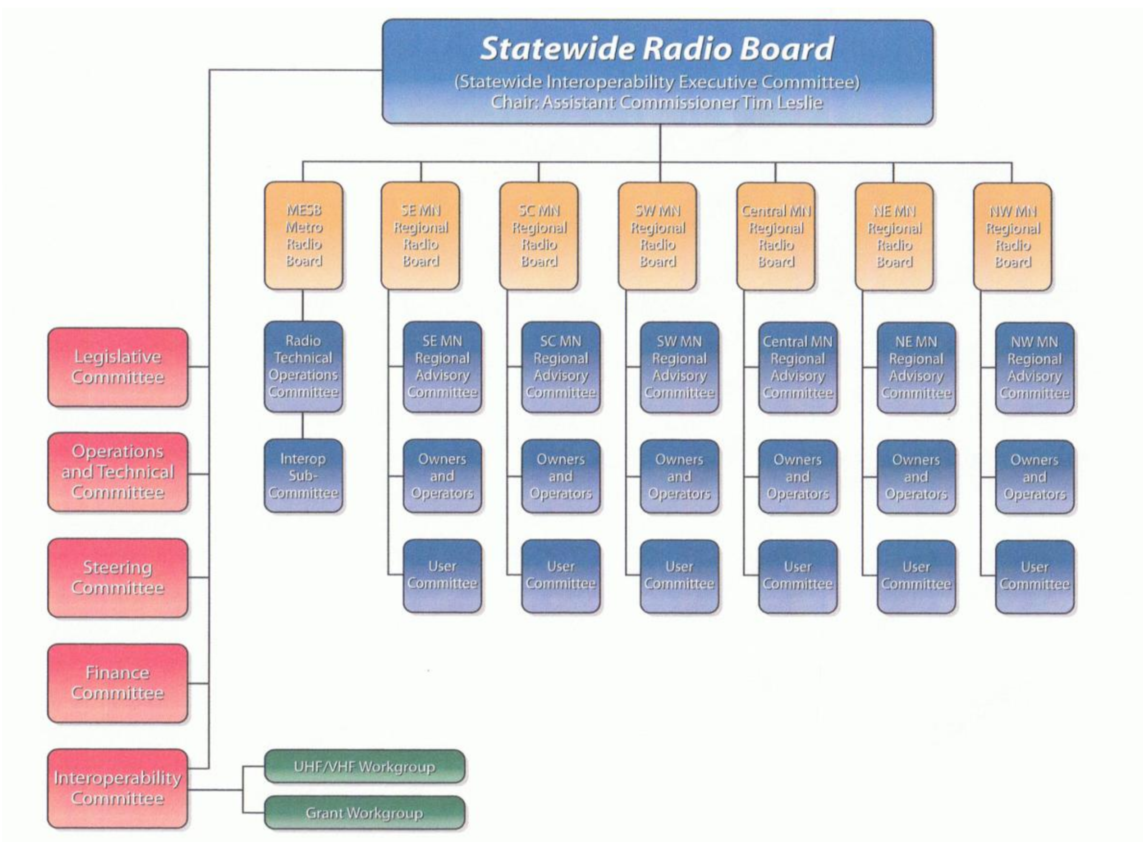
At the end of 2008 every county and most major cities in Minnesota have become part of this governance structure through passing a joint powers agreement and joining a Regional Radio Board. Minnesota State Statute 403.39 defines the following seven Regional Radio Boards (RRB): Northwest Regional Radio Board, Northeast Regional Advisory Committee (predicate to RRB), Central Minnesota Regional Radio Board, Metropolitan Emergency Services Board, Southwest Regional Radio Board, South Central Regional Radio Board, and Southeast Regional Radio Board. The map on the following page displays the boundaries of each RRB's region.



While many states and Metro regions in the United States are planning or implementing systems that are somewhat similar to ARMER in technology, few have been able to replicate the unique shared governance and management model that guides ARMER. Minnesota's governance structure is noted as part of this report because, not only is the SRB responsible for the ARMER plan implementation and operational standards, it is the single most important element for fostering an environment whereby partnerships are formed, collaboration is understood, and all entities can come together to solve the radio communications interoperability problems that have plagued emergency responders for decades.

In the focus groups and video interviews conducted as a part of this project a reoccurring theme was how the governance structure allowed for the building of relationships throughout the development of the system and how the standards created by the governance participants allowed for a more effective response to the I-35W bridge collapse. Building strong relationships of trust and collaboration was perhaps the single most important element for creating a shared system that had the necessary equipment, technology, and standards in place for an event the size of the bridge collapse.

Below is a graphic of the Minnesota's radio governance organization chart. As governance is one of the five essential elements for solving interoperability, as noted by the federal government, Minnesota's bottom-up governance structure has been widely regarded across the country as nation-leading.



Technical Analysis of System Performance

Since a trunked radio system is, at its core, a computer-based and controlled system in which every subscriber radio needs to interact with the system's main control channel to know what frequency to be tuned to as well as to be granted radio channel access to conduct communications on whatever frequency the computer assigns, it stands to reason that every subscriber radio is uniquely identified via an Electronic Serial Number (ESN), and that all transactions of all radios can be logged in the trunked system's central computer.

All of this transactional activity can be queried in a number of different ways and one can begin to develop data snapshots of how the system, a group of radios, or a specific radio was used and/or performed during any defined time period.

The Mn/DOT Office of Electronic Communications and the Hennepin County Sheriff's Office Radio Division are the primary technologists and administrators on the main components of the Metropolitan ARMER system that was used for this event. Both entities have been very forthcoming in providing hard data and assisting in the interpretation of it for the purposes of this analysis.

The "Three C's" of Radio System Performance

In analyzing the technical performance of such a radio system, there are three main areas that need to be studied. They represent the "Three C's of Radio Communications":

1. Radio signal **coverage** for the system.
   a. How well did radio signals perform in getting to field radios?
   b. How well did field radios perform in getting their signal to the nearest receiver site for the system?
2. The **capacity** of the system to meet the demand for talk-paths during peak activity.
3. The audio quality and signal **clarity** provided. In essence, how well could people be understood?

Coverage

The ARMER system provided flawless signal coverage, even in the difficult area presented by a 75-100 foot ravine into the river bottom under the bridge's location.

Unlike much of its some 1,200 miles of travel, the Mississippi River in downtown Minneapolis is not a wide, placid meandering river. Rather, the very existence of Minneapolis is tied to the fact that at this very spot there existed one of the very few actual waterfalls on the Mississippi (St. Anthony Falls). The major drop in the level of the Mississippi between North Minneapolis and South Minneapolis approaches over 100 vertical feet, and while this all tumbled over St. Anthony Falls in the 1850s, it is now harnessed via two locks and dams and two regulated spillways. This means that the I-35W roadway as it crossed the river was some 100 feet above the level of the water beneath it, with literal cliffs rising on both banks, most noticeably on the west bank, the side on which downtown Minneapolis is located. Consequently, when the bulk of the bridge deck collapsed, it collapsed most of the way down to the river, or as much as 100 feet. This means that many of the responders actually working on the collapsed bridge deck and in the water were up to 100 feet below the prevailing land level on top of the cliffs. This would be not unlike working in a ten-story basement, and, had there not been good signal strength or readily accessible system receivers in the area (from several nearby transmitter sites), signal coverage could have been a problem, since radio signals tend to go in straight lines and not flow downward, such as over the edge of a river bank.

Based on the responses provided to our user survey, nearly 95 percent of the users reported solid clear radio signals being heard. Additionally, comments by experienced radio users as well as system technologists who were at the scene and were a part of our focus groups were all in agreement on the performance of the system from a signal coverage perspective.

From a technical performance perspective, a digital radio system largely operates on an "it is either there or it is not there" basis, with few signs of gradual signal degradation. Consequently, if the data collection components of the system captured the existence of a transmission, it can generally be assumed that the transmission was there, in the sense that it contained enough digital bits to pass the Bit Error Rate (BER) threshold to pass through the system. Had a transmission contained too many bit errors, it would not have been recognized by the system and not passed.

The photos on the following pages depict the elevation extremes between the I-35W roadway and the level to which the bridge fell.

From the downtown Minneapolis side, showing the bridge before collapse and depicting the vertical distance from the bridge deck down to the river itself. (The river flows from left to right.)

From the downtown Minneapolis side (but downriver from the above photo) showing how far the bridge fell and how far below road level the rescue work was being done. The standing bridge is the 10th Avenue bridge, which ran parallel to the I-35W bridge as can be seen.

Looking at the collapse site on the northeast Minneapolis side of the river (across the river from downtown) showing police officers, firefighters, and civilians shortly after the collapse.

Overall view of the collapse site from the northeast Minneapolis side of the bridge. The standing bridge towards the bottom with all the people on it is University Avenue Southeast.

Capacity

The ARMER system significantly met the capacity requirements at the incident scene, but there were some capacity issues further away from the scene, which were greatly impacted by distant radio user decisions.

In the vast majority of cases, when radio users near the bridge pressed the "Push to Talk" (PTT) button on their radio or its microphone to initiate a request for a talk-path to be assigned (a split-second electronic transaction) to them for their transmission, they were provided with a "channel grant" and were permitted to talk on their selected talk-group instantly. In our user survey, 83.1 percent of the respondents reported they could access the system without delay or with only an occasional short delay.

- In cases where no channel resources were available for an instantaneous "channel grant," the user received a noise from the radio, commonly referred to as a "bonk tone," telling them that no channel resources were available at that instant, but that they were now in queue for the next available channel resource appropriate to the pre-set priority level of the talk-group they were selected to.
- A few ARMER users did receive these "bonks" near the bridge, but detailed analysis of the system data collected at the main system controllers reveals that many of these users were from one specific user agency, and that the access priority assigned to the talk-group that this small group of users had chosen to use during the incident was Priority 7, and that had these users used one of the established Priority 3 incident talk-groups (METTAC, PTAC, or a FTAC, for example) they would have experienced far fewer "bonks," since they would have been competing on an equal footing with other users accessing the system at the higher priority and would not have encountered anywhere near the busy tones they did.

The Theory and Application of "Talk-group Priorities"

By way of reminder, a "talk-group" is essentially an electronic "meeting room" to which radio users who choose to participate in a series of communications are electronically assigned for the purpose of talking or listening in on that series of communications, and they stay there until they choose to or are directed to enter some other "meeting room" by changing their selected talk-group. For example, Minneapolis Police Department (MPD), police officers in the 3rd Precinct generally have their car and portable radios selected to the talk-group known as "MPD Precinct 3," which replicates the functionality that used to be carried over radio channel 1 in the old conventional, non-trunked six channel MPD UHF radio system. There are several general classifications of the dozens to hundreds of talk-groups that exist and are used (to widely varying degrees) by the many ARMER system users. Each of these several categories of talk-groups is pre-assigned a priority within the system for access to channel resources. These pre-programmed priority settings only become relevant when there is a competition for talk-path resources. The general categories and the access priority levels for many of these talk-groups are:

- **Priority 1:** When the orange EMERGENCY button is pressed on any subscriber radio. This sets up a Priority 1 emergency talk-group allowing that user radio to take precedence over all other radios that are seeking a channel grant in order to talk.

- **Priority 3:** Reserved for major interoperability, joint operations tactical talk-groups such as METTACs, PTACs, FTACs, and ETACS. (P, F, and E stand for police, fire, and EMS, and TAC stands for tactical, while MET means Metro.)
- **Priority 5:** Main dispatch talk-groups. This would include an agency's main police, fire, and EMS talk-groups over which their units are regularly dispatched to pending events.
- **Priority 7:** Administrative talk-groups such as "Agency X, car to car," etc.
- **Priority 10:** "Private call" and "telephone interconnect" usages. In this trunked system it is possible for one radio to direct a private radio call specifically to another single radio. This is generally done by supervisors who have key-pads on their radios. Another capability is for a specially equipped (not many are) field radio to affiliate itself with a landline telephone dial-tone and place a regular public switched telephone network (PSTN) telephone call through the radio system. Both of these usages are considered low priority due to the fact that they consume an entire radio channel to support the needs of only two people (the talker on either end) and are prioritized as such for access to resources.

Priority levels 2, 4, 6, 8, and 9 are not permanently assigned to talk-groups in the ARMER system. They are set aside for dispatchers to tactically upgrade the access priority of a given talk-group via a simple mouse click on their dispatcher console screen for the limited duration of an event, such as a police pursuit. For example, a dispatch talk-group with a normal Priority of 5 could be temporarily upgraded to a Priority of 4 by a dispatcher managing an incident on that talk-group.

To sum up capacity and access priority, if 500 radios are operating in a small area, and in that area there are tower sites with 30 functional trunked radio channels, that means that 29 different and concurrent radio transmissions can be taking place at any one instant, each on a different talk-group, with the 30th channel being retained by the system to be used as a control channel. If, during the duration of this incident in this area there is never an attempt by anybody to use a 30th talk-group while the other 29 are in use, then there will never be contention and talk-group priority would not be an issue. However, as soon as someone tries to use the 30th (and beyond) talk-group concurrent with the usage of the 29 other talk-groups (does not matter which other 29 it might be), then there is competition, and the persons using the talk-group with the higher priority will get access before persons using talk-groups with lower priority.

Having higher talk-group priority does not mean (at least in the way the ARMER system is programmed) that a higher talk-group user "ruthlessly preempts" a lower priority user and knocks them off the air, mid transmission. Rather, it means that the higher priority talk-group user will go ahead of the lower priority talk-group user in the queue for channel resources, but only when there is contention.

The extent to which there are many more talk-groups in a trunked radio system than there are radio channels available at any one place is a significant determinant of the degree to which competition for a channel grant is a potential. If, for example, there were 29 available channels, but only 25 total talk-groups of any priority, channel competition could never occur, because there are no more than 25 groups of people trying to meet in 29 electronic meeting rooms. Granted, a given person using one of those 25 talk-groups might have a hard time "talking in the desired meeting room" due to lots of folks "in the room" talking, but they would not be electronically denied access to that room or the talk-group.

In developing our user survey instrument, we separated the "electronic system denial" issues ("bonks" due to lack of channel resources) from the issues of too many people trying to say too many things over one talk-group, resulting in human factor contention, which is not a function of system design or capacity.

There are two significantly more complex technical issues relating system capacity that must be mentioned and explained. These issues are described as:

- Excessive remote location capacity demands far away from the bridge scene.
- Configuration of the ARMER system as it relates to the "personality" of a communication on a given talk-group.

The "excessive remote location capacity demands on the system" issue can be very confusing. It is important to remember that for any communication to be transmitted from an ARMER system repeater in any given location; there must be an available radio channel/repeater at that location free to broadcast that voice transmission.

Add to this understanding the awareness that the number of ARMER system repeater channels installed at any given tower site was determined during the system's design phase by the expected capacity demand in that area, in combination with the availability and usability of radio frequencies for those repeaters at that tower site. (Refer back to the diagrams earlier showing the ARMER system architecture.) For example, at a tower site in a sparsely populated area in the far corner of the Twin Cities Metro area, it may have been decided that five repeater channels would be adequate, while at a tower site in downtown Minneapolis, it may have been decided that over 20 channels were required.

The I-35W bridge collapse event:

- Commanded major interest from public safety personnel nationwide, as well as wall-to-wall live television news coverage.
- Required intense awareness by all public safety personnel throughout the Twin City Metro area, all of whom could rightfully assume that this might become an "all call" situation requiring, if not direct responses by them from dozens of miles away, at least responses to back-fill empty fire stations and police patrol areas vacated by closer in responders massing at the scene.
- Was facilitated by a wide area two-way radio system in which almost all potential public safety responders as well as many public service users actually had the ability to listen to and (if necessary) talk to participants right at the scene.

As such, if a firefighter for a volunteer fire department in a remote corner of the Twin Cities Metro area, or a patrolling deputy sheriff 40 miles from the scene had been told about the incident and were placed, essentially, on stand-by to do something (perhaps yet to be determined), it would be natural for that person to find on their ARMER radio the mutual aid talk-group or talk-groups that were in use by their area of specialty at the bridge collapse scene, select them and listen in.

Who would not be tempted? However, this well intentioned "listening in" to the bridge collapse events by emergency personnel not directly involved created some significant capacity issues for those remote areas.

Around that fire station in the far corner of the Metro area, there are only one or maybe two ARMER system towers providing radio signal. Each of them might have five channels operational, with four available to support voice and one for the system control channel. Assume two firefighters at that station were to take two ARMER radios and select the talk-groups known as FTAC1 on the first one and FTAC2 on the second one. Now assume a nearby patrolling deputy finds the talk-group PTAC1 in use at the bridge scene on his portable radio and listens in while keeping his patrol car two-way radio selected to his department's main dispatch talk-group. Then the local EMS service provider switches one of their ARMER radios to the ETAC1 talk-group, which is in use at the bridge scene.

There would now be four radios in this remote area all standing-by to receive transmissions on FTAC1, FTAC2, P-TAC1, and ETAC1, four different Priority level 3 talk-groups that are in use at the bridge collapse.

Recall that ARMER is a simulcast system, but more specifically, it is a simulcast on demand system. In a straightforward simulcast system (which does not operate under "on demand"), every transmission on every talk-group is presumed to be of potential interest or value to every radio user everywhere within that system's coverage area, so all transmissions are simultaneously broadcast from each of that system's several tower sites all at once, all the time. Even if it is one portable radio in a far corner of a county, talking to another portable radio one block away, the transmission is simulcast from all tower sites for that system, system-wide (in the case of the Twin Cities region, over all nine counties). Because of this, all tower sites of that straightforward simulcast system would each have the same number of channels at each site.

However, the ARMER system asks itself fundamental question every time a transmission is about to be simulcast: Is there anybody out there, in this specific area or zone, that cares about this forthcoming transmission, as evidenced by the fact that they are in this area or zone and they have selected the talk-group on which this transmission is about to be carried?

Typically, for a routine radio transmission between a patrolling Minneapolis police car and its dispatcher, not only would no patrolling deputy in a sheriff's office 40 miles away care or be interested in the transmission, the distant deputy's radio would likely not even be programmed with the talk-group on which the Minneapolis officer is conducting the routine transmission. That would mean that even if he was interested, he could not monitor because he did not have the ability to select that talk-group on his radio.

Therefore, the answer to the question, "Is there anybody out there who cares about this transmission on this talk-group?" in this example would be no, and since there would be no demand for that transmission in that remote area, there would be no simulcast of that transmission into that remote area, and no channel resource would have been used to broadcast that transmission in that remote area. For this routine MPD communication example, channel resources would only have been used at tower sites where some radios were affiliated which had selected that talk-group and/or at which a given talk-group had been pre-assigned for transmission. (Some talk-groups are programmed as appropriate for wide area transmission due to the far and wide roaming of the user of that talk-group).

Now, change this scenario a little bit by putting the Minneapolis officers over on an area-wide special event tactical talk-group (PTAC1, for example) to which every law enforcement radio has access. When the distant county deputy selects PTAC1 to listen to what is going on, a demand is being created in the distant deputy's geographic area for the broadcast of that radio traffic on PTAC1, which will require a channel resource in the distant deputy's geographic area every time something is said on the PTAC1 talk-group. Now multiply this situation by FTAC 1 and 2 being monitored in the distant fire station in the same area as the deputy, and ETAC1 being monitored at the nearby local hospital and it is easy to see that whenever all four talk-groups are in use at the same time (which would have been quite often on the evening of August 1, 2007) all the channel resources in this distant area could be used up broadcasting the many transmissions being carried over these Priority 3 talk-groups.

The listening in or using of these resources creates an additional problem in that the main dispatch talk-groups are Priority 5, which is a lower priority than the talk-groups being listened to in this example. Therefore, under this scenario, it is conceivable that a few "bonks" would have been heard in this distant area when people were trying to contact their own dispatcher on their own dispatch talk-group from within their own geographic area. The table on the next page highlights this issue.

Detailed Busies of 20+ Seconds	All Zones	All Sites	8/1/07: 1800	To 8/2/07: 0600		
Date and Time (all 8/1/07)	**Radio ID**	**Radio Alias**	**Target Talk-group Name**	**Name of Serving Transmitter Site**	**Busy Sec.**	**Busy Reason**
7:34:17 PM	101716	DNR-K376-M	DNR-EAST	CITY CENTER	95.2	Resource not available
7:35:10 PM	103442	ID$103442	DOT-PAVING	CITY CENTER	78.7	Resource not available
7:34:56 PM	105596	EMSRV CS1	EMSRV-ALS	NORWOOD	66.9	Resource not available
7:46:56 PM	101710	DNR-K300-M	DNR-EAST	CITY CENTER	39.2	Resource not available
7:34:35 PM	100760	MNHSEM-721-P	MN-HSEM-MAIN	CITY CENTER	35.4	Resource not available
7:34:30 PM	103442	ID$103442	DOT-PAVING	CITY CENTER	30.2	Resource not available
7:05:40 PM	107133	EMSHE HET BASE	ID$2296	CITY CENTER	29.9	Resource not available
7:37:41 PM	101635	DNR-K019-P	DNR-WEST	CITY CENTER	25.7	Resource not available
7:46:47 PM	100378	MSP-358-M	MSP-2500 C2C	LINO LAKES	25.7	Resource not available
7:40:50 PM	113049	MP 113049	MP 113044	MPLS	24.3	No busy reason
7:44:12 PM	103971	DOT-M21-P	DOT-TAC1	CITY CENTER	24.2	Resource not available
7:32:15 PM	101716	DNR-K376-M	DNR-EAST	CITY CENTER	23.4	Resource not available
7:23:42 PM	101737	DNR-K352-M	DNR-EAST	LINO LAKES	23.3	Resource not available
7:45:59 PM	103547	DOT-2607-P	DOT-ARDEN-HLS	CITY CENTER	22.6	Resource not available
7:34:04 PM	108048	MCME6193	MCME1	CITY CENTER	22.0	Partial busy
7:30:56 PM	100118	MSP-CAR17-P	MSP-2000	CITY CENTER	21.6	Resource not available
7:44:18 PM	105672	EMSAL-643-P2	EMS WEST MRCC	CITY CENTER	21.6	Resource not available
7:35:19 PM	121261	US-ATF02-P	H-VOTF-1	HASTINGS	21.4	Resource not available

Fast Start versus All Start Talk-group 'Personality'

There is a related and even more technical problem and it is referred to as the "Fast Start" versus "All Start" personality assigned to a given talk-group when the talk-group is created. This issue also impacted system performance during the bridge collapse.

When creating a talk-group in a simulcast system, the system administrator must define whether a transmission on that talk-group will be permitted to proceed (a talk permit tone being issued to the requesting radio) when one of the following two criteria are met.

Channel resources are available and assigned at all tower sites to which radios that have selected the talk-group are affiliated. (This goes back to the "demand" situation described above.) Is there a demand in a given tower's service area for somebody to hear something on this talk-group? If yes, then there needs to be a channel resource at that site to carry that transmission out to that interested party's radio. So, if in setting up that talk-group, system technicians responded, "Yes, a planned transmission on this talk-group will only be granted a talk permit tone when there is a channel available to carry this transmission at All Sites from which it needs to be transmitted;" then the All Start mode of operation would have been selected, meaning that the transmission cannot start until all affected/required tower sites are ready with an available channel for use.

OR

The talk permit tone will be issued as long as there is at least one channel resource at one site of the (perhaps) many sites from which the transmission will need to eventually emanate. This means that radios in some areas may not receive the transmission from the beginning, but that they will pick it up midstream once channel resources become available in their area. This is referred to as the Fast Start mode or behavior.

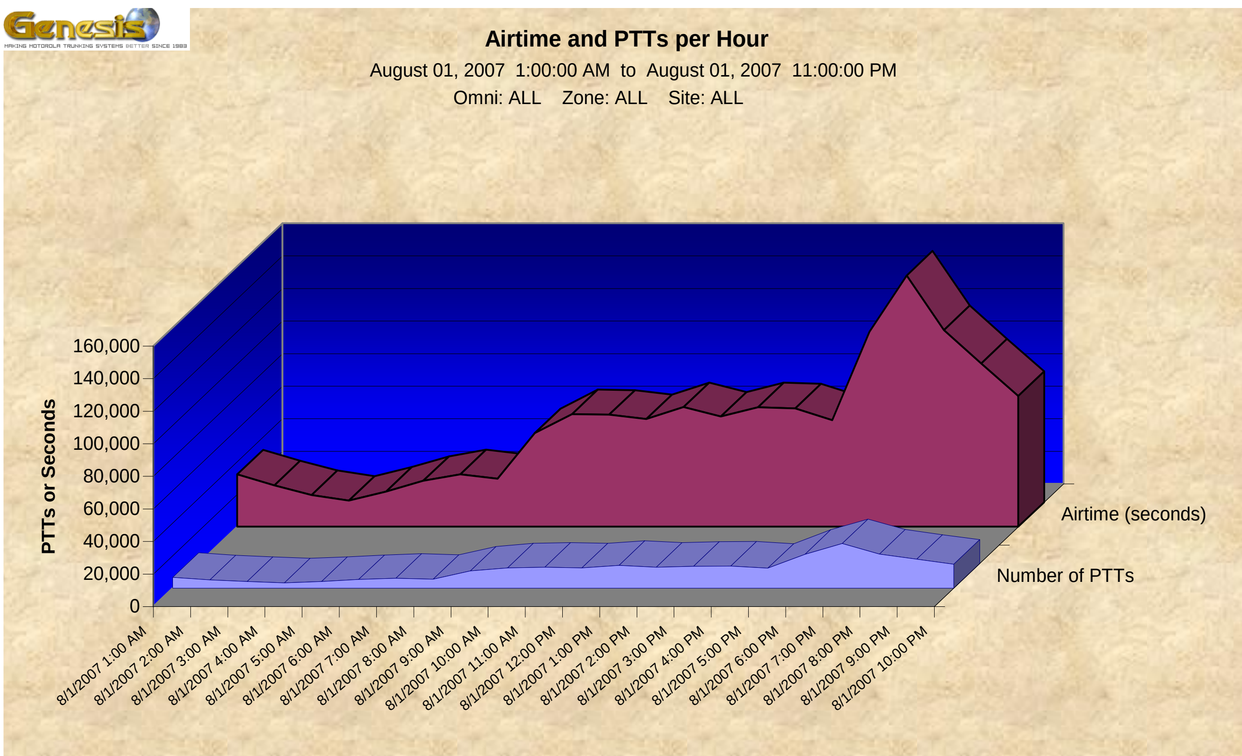
The significance of these issues is now documented. The more radio users in more places that choose to listen to a given talk-group, the more the chances are that there will be channel resource issues (meaning "bonks" when channels are not available to support a transmission). This is compounded when several to many higher priority talk-groups are used in a given incident.

For example (and this is not operationally valid), had only one Priority 3 TAC talk-group been used during the bridge incident, no more than one added transmission would have ever needed to be carried over limited channel resources at remote sites, and the likelihood of this problem occurring would have been greatly reduced. Of the most significance is the fact that if All Start is employed on a talk-group, the risks of a busy being encountered due to not enough channel resources being available across all tower sites is dramatically increased, particularly if there are radios in the coverage area of many to all of those tower sites that have selected (tuned to) the talk-group in question.

In general, the All Start mode had been previously selected for some of the ARMER system's talk-groups at the outset, and this is now being re-visited due to the above lessons learned. More specifically, the ARMER system administrators are becoming far more aware of these issues and their ability to tactically plan around them when planned events are conducted (such as the RNC in St. Paul in September 2008).

Other ARMER System Performance Metrics

From the many sources of captured data on the ARMER system's performance during this incident, the following serve to illustrate some of the more relevant points this report has discussed. The diagram below graphically captures the tremendous increase in use of the ARMER system at the time of, and for some time after the bridge collapse. The light blue axis showing "Number of PTTs" (meaning Push to Talk actions) reflects attempts to access the system for communications. The purple axis shows the number of seconds of "airtime" supported by the system. Not only did the number of PTTs go from 12,256 in the 5-6p.m. hour to 27,732 in the 7-8p.m. hour (an increase of 123 percent), but the number of minutes of airtime went from 1,091 in the 5-6p.m. hour to 2,572 in the 7-8p.m. hour, an increase of 136 percent.



The following table shows the "grade of service" performance of the system. Look, for example, at the "Hastings" site. This is a remote site in the far southeast sector of the Metro area, many miles away from the bridge scene. At that site there are six voice channels. There were 2,732 requests for channel grants during the 7-8p.m. hour. Those channel grants consumed 17,621 seconds. There was a cumulative 2,652 seconds of "all channels busy" at that site during the 7-8p.m. hour, resulting in 466 momentary instances of all channels being busy. The average busy duration lasted 5.7 seconds, and there were 264 instances of a busy duration exceeding 3 seconds, at this site, many miles away from the bridge scene. In the aggregate, all this means that at this site, the system was fully used 81.58 percent of the available time during the 7-8p.m. hour. It seems quite apparent that this site (along with the Norwood site and the Hennepin West site) was significantly impacted by the "remote monitoring" phenomenon discussed in the body of this report. **Important:** An "all channels busy" is not the same as a "system busy." In an "all channels busy" condition, there may not be anyone trying to gain that one more channel, and therefore, no "system busies."

Site Alias	Busy Hour	"PTT" Requests	Requested Time (Sec.)	Avg. Channel Busy Duration (Sec.)	Voice Channels at this Site	Site Utilization Rate
HASTINGS	7:00 PM	2,732	17,620.8	5.7	6	81.58 percent
NORWOOD	7:00 PM	3,075	18,993.5	5.5	8	65.95 percent
CITY CENTER	7:00 PM	10,077	59,723.7	3.8	20	82.95 percent
HENN CNTY WEST	7:00 PM	5,136	30,556.3	5.6	12	70.73 percent
LINO LAKES	7:00 PM	6,002	36,573.7	4.1	13	78.15 percent
NORTH BRANCH	7:00 PM	2,098	12,439.9	3.6	6	57.59 percent
WCAL	7:00 PM	1,891	11,432.7	4.3	6	52.93 percent
HENN CNTY EAST	7:00 PM	8,898	50,780.6	1.6	23	61.33 percent
RAMSEY	7:00 PM	5,661	34,716.0	4.5	19	50.75 percent
KIMBALL	7:00 PM	693	4,471.2	0.0	4	31.05 percent
FREEDHEM	7:00 PM	793	4,368.3	0.0	4	30.34 percent
KINGSTACK	7:00 PM	1,539	9,616.0	0.0	7	38.16 percent
FARMINGTON	7:00 PM	598	3,713.4	0.0	5	20.63 percent
AVON	7:00 PM	398	2,473.6	0.0	5	13.74 percent
MINNEAPOLIS	7:00 PM	4,738	29,431.3	0.0	18	45.42 percent
OLMSTED	7:00 PM	887	5,385.9	0.0	8	18.70 percent
GROVE	7:00 PM	162	862.6	0.0	5	4.79 percent
BELGRADE	7:00 PM	158	837.8	0.0	5	4.65 percent
ST CLOUD	7:00 PM	487	2,580.4	0.0	7	10.24 percent
Data Provided by Genesis	7:00 PM	**56,023**	**336,577.7**	**336,577.7**		

Detailed Technical Information

We have reviewed dozens of complex data reports and spreadsheets that document the ARMER system's performance during the bridge collapse in order to arrive at the conclusions expressed in this report. Many of these data sources are too large or arcane to reproduce here. But we have found several reports which are particularly illustrative, and we are reproducing them here.

The table below shows the system activity in terms of the number of "Push to Talk" activities at various one hour intervals. Note that between 7:00p.m. and 8p.m. (the bridge collapsed just after 6p.m.) the number of system access attempts (27,372 "Push to Talk" or PTT activities) was 220 percent higher than at noon on the same day. Similarly, the total seconds of system usage during this 7-8p.m. period was 233 percent higher than the number of seconds of usage during the noon hour the same day.

Date/Time	Number of PTTs	Airtime (seconds)
08/01/2007 01:00:00 AM	6,701	32,154.2
08/01/2007 02:00:00 AM	5,141	25,453.1
08/01/2007 03:00:00 AM	4,084	19,467.2
08/01/2007 04:00:00 AM	3,264	15,991.3
08/01/2007 05:00:00 AM	4,159	21,616.8
08/01/2007 06:00:00 AM	5,308	28,203.6
08/01/2007 07:00:00 AM	6,077	32,245.4
08/01/2007 08:00:00 AM	5,452	29,498.0
08/01/2007 09:00:00 AM	10,563	57,453.2
08/01/2007 10:00:00 AM	12,448	69,181.5
08/01/2007 11:00:00 AM	12,870	68,816.5
08/01/2007 12:00:00 PM	12,433	66,129.1
08/01/2007 01:00:00 PM	14,041	73,437.4
08/01/2007 02:00:00 PM	12,859	67,642.0
08/01/2007 03:00:00 PM	13,484	73,374.6
08/01/2007 04:00:00 PM	13,626	72,705.1
08/01/2007 05:00:00 PM	12,256	65,481.4
08/01/2007 06:00:00 PM	20,785	119,718.6
08/01/2007 07:00:00 PM	27,372	154,313.9
08/01/2007 08:00:00 PM	20,990	120,820.1
08/01/2007 09:00:00 PM	17,804	100,240.6
08/01/2007 10:00:00 PM	14,736	80,299.4
Data Provided by Genesis	256,453	1,394,243.0

Airtime and PTTs per Hour		
Omni	Zone	Site
ALL	ALL	ALL
Start Date:	08/01/07 01:00:00 AM	
End Date:	08/01/07 11:00:00 PM	

The table below details the number of radios that were turned on at 7:30p.m. on August 1, 2007, and were affiliated with a given site in the ARMER system.

Site Affiliation Summary				
Omni	Zone	Site		
All	All	All		
Date/Time:	08/01/2007 07:30:00 PM			
Omni	Zone	Site	Site Name	Affiliations
1	1	1	CITY CENTER	3,000
1	1	2	LINO LAKES	1,744
1	1	4	NORWOOD	845
1	1	5	HASTINGS	303
1	1	6	NORTH BRANCH	100
1	1	7	KINGSTACK	167
1	1	8	WCAL	125
1	1	9	MPLS	2,222
1	1	24	FREEDHEM	20
1	2	1	HENN CNTY EAST	4,281
1	2	2	HENN CNTY WEST	920
1	2	3	RAMSEY	1,648
1	2	13	KIMBALL	51
1	2	15	FARMING	106
1	2	16	AVON	107
1	2	17	GROVE	74
1	2	18	BELGRADE	15
1	2	19	ST CLOUD	675
1	2	20	OLMSTED	132
Data Provided by Genesis				16,535

Total of main sites accessed by most users during the bridge collapse: (in red above) = equals 11,151 radios. If one adds the Lino Lakes site (just north of Minneapolis on I-35W, where traffic was backing up significantly) and its 1,744 affiliated radios, the total comes in at 12,895 radios active in and near the bridge collapse scene at 7:30p.m.

Digging Into "System Busy" Data

We have analyzed reports which detail the incidence of "system busies" (what happens when a radio user presses the PTT button and the ARMER system in that area of operation has no radio channels available to support the desired communication) during the 12 hours from 6:00p.m. on August 1, 2007, (5 minutes before the collapse) to 6:00a.m. on August 2, 2007, at 7 of the ARMER system's regional sites, as follows:

- The City Center sites, which serve primarily state and regional units
- The Minneapolis sites, which service primarily City of Minneapolis subscriber radios
- The Hennepin East sites, which serve primarily Hennepin County and suburban units
- The Lino Lakes sites, which primarily serve Anoka County and state units
- The Ramsey sites, which primarily serve Ramsey County and St. Paul units
- The Hennepin West sites, serving primarily west Hennepin and Carver County units
- The Norwood sites, serving primarily state and Carver County units on the west

The highlights of this review are as follows:

- The single longest case of system busy occurred at 7:34p.m. when a DNR enforcement officer was denied system access for 95.2 seconds. This radio was seeking access via the DNR east talk-group, which is has a Priority 7 access level.
- The second longest system busy was at 7:35p.m. when a Mn/DOT paving crew radio attempted access and was denied for 78.7 seconds, using a DOT Paving talk-group with an access Priority of no greater than 7.
- At the City Center sites alone, in the one hour from 7-8p.m. there were 10,077 "Push to Talk" channel requests. Then, for the 12 hours from 6p.m. to 6a.m.:
  - There were a total of 38 instances of system busies exceeding 10 seconds during this time period. Of these 38 instances, in only one instance was the user operating on a Priority 3 mutual aid/interoperability tactical talk-group, and that instance was at 7:32p.m. involving an HCMC ambulance and it lasted for 15.5 seconds on the ETAC1 talk-group. All other cases occurred when users were operating on lower access priority talk-groups.
  - Out of the top 200 instances of system busies occurring through City Center (which go all the way down to busies lasting only 2.4 seconds), the average duration of a system busy for persons operating on the appropriate Priority 3 mutual aid talk-groups was 4.8 seconds each.

- At the Minneapolis sites there were 4,738 PTTs during the 7-8p.m. busy hour, while over the 12 hours from 6p.m. to 6a.m.:
  - There were only 3 instances of system busies exceeding 10 seconds. All 3 of these involved "private call" communications (private radio to radio) which are assigned access Priority 9 at 6:14, 7:36, and 7:40p.m.
  - Out of the top 100 instances of system busies on the Minneapolis system (which go all the way down to durations of only 0.9 seconds), while fully 50 attempts using a Priority 3 mutual aid talk-group encountered busies, of these instances of busies only 23 user radios encountered busies of longer than 2.0 seconds, with the remaining 27 lasting 1.9 seconds or less.
- At the Hennepin East sites, there were 8,898 PTTs during this 7-8p.m. busy hour, while over the 12 hours from 6p.m. to 6a.m.:
  - There were also only 3 instances of busies lasting 10 seconds or longer, with none of them occurring on Priority 3 mutual aid talk-groups.
  - For the top 100 instances of system busies on the Hennepin East system (which go down to durations of only 0.7 seconds) there were only 6 encountered while using Priority 3 mutual aid talk-groups, with the average busy duration for these 6 being 1.87 seconds.
- At the Norwood sites, there were 3,075 PTTs during the 7-8p.m. busy hour, while over the 12 hours from 6p.m. to 6a.m.:
  - There were 6 instances of busies lasting 10 seconds or longer, with 5 of them involving EMS units and 1 a fire unit in Carver County. The longest of these was for 66.9 seconds, and none of these 6 instances occurred while using Priority 3 mutual aid talk-groups.
  - For the top 70 instances of system busies on the Norwood sites (there were only 70, going all the way down to 0.1 seconds), only 1 lasting 0.5 seconds was on a Priority 3 mutual aid talk-group. There were several instances of a Minneapolis radio using a Minneapolis Police Department talk-group (MPPD7) which is a Priority 5 (or lower) talk-group.
- At the Hennepin West sites, there were 5,136 PTTs during the 7-8p.m. busy hour, while over the 12 hours from 6p.m. to 6a.m.:
  - There were 2 instances of system busies lasting 10 seconds or longer, with none of them occurring on Priority 3 mutual aid talk-groups.
  - For the top 74 instances of system busies at this site of over 0.1 seconds (there were only 74 such instances) only 1 occurred on a Priority 3 talk-group (P-TAC-1Z1) and that lasted only 0.3 seconds.
- At the Lino Lakes sites, there were 6,002 PTTs during the 7-8p.m. busy hour, while over the 12 hours from 6p.m. to 6a.m. there were:
  - Ten instances of system busies of 10 seconds or longer, with the longest being for 25.7 seconds. None of these 10 instances occurred on talk-groups carrying access Priority 3.
  - For the top 100 instances of system busy at this site, going down to busy delays of 1.3 seconds, there were only 2 such occurrences over Priority 3 mutual aid talk-groups, and they were for 2.9 and 2.3 seconds each.

- At the Ramsey site, there were 5,661 PTTs during the 7-8p.m. busy hour, while over the 12 hours from 6p.m. to 6a.m.:
  - There was only one system busy exceeding 10 seconds, and that was for 11.8 seconds at 7:42p.m.
  - For the top 100 instances of system busy at this site, going down to 0.2 seconds duration, 8 occurred while using Priority 3 mutual aid talk-groups.

This analysis supports the observational data obtained in our survey and confirms that the concept of talk-group priority did its job, meaning that those persons using the higher priority talk-groups had far better success at accessing the system during periods of peak activity, and that is how it should be.

However, this data does not provide definitive answers to the following questions:

- Are there enough channels at each and all the sites?
- Is training adequate for all users (including dispatchers) in determining which talk-groups to use at which times, so as to take advantage of the power of this prioritization?
- Are all talk-group access priority assignments appropriate given the experiences of August 1, 2007?

As it relates to whether or not there are enough channels at every site, it would appear as if given the way talk-group priorities are assigned, and given the way talk-groups were used on August 1, 2007, there is a justifiable need for additional surge capacity at the City Center site.

As it relates to the question of training, based on our survey data and input received at our focus groups it would appear that there is a large gap between what could be known and be of value in decision making regarding talk-group usage and what is actually known. In order to maximize system utility and capacity, the Statewide Radio Board is urged to adopt standards requiring greater training on these issues.

As it relates to the appropriateness of talk-group priorities for their intended usage, anecdotal information, as well as some observed data indicate that there is the need (given the lessons learned in this experience) for a thorough audit of talk-group priorities as well as regular re-audits as the system is built out statewide, and more and more talk-groups are added to the system.

Clarity

The ARMER system fully met the audio quality and voice clarity requirements of its users during the bridge incident.

As referenced earlier, the ARMER system is a digital radio system. This means that the radio signals traveling through the air are made up of packets of 1's and 0's (binary digits, hence the term digital) instead of analog waves containing human voice sounds. Consequently, if an adequate number of 1's and 0's arrive at a receiver radio, that receiver can re-constitute those 1's and 0's back into an audio packet that sounds very much like the original noise before it was digitized.

Digital two-way radio is fairly new to two-way radio users, and all of the legacy systems replaced by ARMER were analog systems.

Based on our survey findings, the superior audio quality of the ARMER digital system was recognized and much appreciated by the users.

There are some issues floating around the United States fire service radio user community about digital radio and problems in the fire service with distorted audio caused by concurrent background noises from some rescue equipment, alarm bells, etc. covering up or distorting the digital bit stream of the voice of the person speaking. Several ARMER expert users and others have studied this issue in depth with real tests in Minnesota and have not been able to recreate the alleged problem.

We sought information on this issue in our survey as well, and it would appear as if there were no such problems reported during the bridge incident, despite the obvious cacophony of car horns, car alarms, power rescue equipment, and the like.

User's Experience and Perception Survey

One method we used for determining how the ARMER system performed during the bridge collapse was to solicit information from the emergency personnel who were directly involved in the response to this event.

A Web-based survey consisting of 16 questions was developed and sought information on the demographics of who was responding to the survey, their role related to the bridge collapse response, and then a series of questions to assess how well the ARMER radio system met user needs during the bridge collapse incident from both a technical and operational perspective.

The survey netted nearly 100 responses from the controlled access, Web-based survey that was made available to the first responders to the incident as well as to dispatchers involved in the incident.

The following is a summary of the questions and responses to each question. The full results and comments, as provided by the survey responders, can read in their entirety in Appendix B.

When asked about being granted access to the system for the purpose of communicating, 83 percent of survey respondents indicated that they could get regular access to the system with an occasional delay. When access was granted nearly 30 percent indicated that it was hard getting air time on their talk-group of choice, while 68 percent indicated that they were generally able to get air time as they needed, and 95 percent of survey respondents reported that the digital audio allowed them to be clearly heard and heard others clearly.

For the purpose of understanding how responders got to the talk-group they used during the event we asked if they decided on their own or were told which talk-group to use. The results indicated that 31 percent decided on their own, 62 percent were directed to the appropriate talk-group, and 7 percent did not recall.

Respondents were asked if they were trained properly on how to use the system and 88.5 percent said yes and 11.5 percent said no. Interestingly, in the comment section of this question a respondent wrote:

> "Training was good for day-to-day use. I believe we all need more training on how to use the system most effectively during major emergencies involving many agencies. Who decides which talk-groups? Who links local tactical talk-groups to regional talk-groups in midstream during the emergency? Example: Initial responding organization begins operations on their own tactical talk-groups. As the incident evolves it is difficult to change use from the local TAC talk-group to a regional. Command deals with operational issues, who manages talk-group assignment or crosspatches? How is this information communicated during operations?"

As airtime impacts system capacity we asked how well the system was used by responders. Did users talk too much, too little, or about the right amount, given the nature and scope of the incident? The purpose of this question was to assess user perceptions about how the system was used, as opposed to how well it worked. Fifty-three percent of respondents indicated that in general users talked about the right amount and 35 percent of users talked some or way too much.

As the reader may know, various fire agencies across the country have reported problems with the voice decoders of digital systems in high noise environments, so we wondered if the event sounds made by people or equipment were a factor in understanding voice communications. While 89 percent responded that they could hear just fine, 11 percent did recommend that users should try to control their voice and be more cognizant of background noises that could be picked up by the radio microphone.

The following summary statement was put forth in the survey about the performance of the ARMER system, and respondents were asked where they agreed:

> "The ARMER trunked system performed very well during the I-35W bridge collapse incident on August 1, 2007, and the several weeks of recovery thereafter."

In total, 96 percent of respondents strongly agreed or somewhat agreed with the statement.

Conclusions

The communication component of I-35W bridge collapse was a large scale event that tested all elements of the ARMER infrastructure:

- The ARMER design in the Metro area, with its multiple redundant paths, proved its operability, interoperability, and effectiveness during the event.
  - The system, which was built for day-to-day activities, is easily able to expand with the size and scope of emergency events.
- The robust, bottom-up governance structure was more important than the equipment that was used to manage the I-35W bridge collapse.
  - It was the people involved in planning the system and developing the procedures that allowed the equipment to be programmed properly and used effectively.
  - Most importantly the relationships that were developed in the planning for this system allowed multiple agencies and jurisdictions to achieve a level of trust that contributed to the effective response and use of the system.
- It can be concluded that the ARMER system provided flawless signal coverage in the difficult 75-100 foot river bottom ravine and that the audio quality and clarity of the voice communications was superior.

In arriving at conclusions regarding the technical performance of the ARMER radio system's capacity on August 1, 2007, it is critical that one clearly establish and understand what elements impact capacity. Some analysts may simplify the evaluation by stating "it worked well because there were enough channels" or "it had problems with system busy conditions due to a lack of channels" or other similar broad conclusions. These statements miss the underlying context of this analysis.

The data indicated that the system experienced heavy usage on the evening of August 1and channel capacity should be added in some areas. However, some users of the system experienced system delays not because of a lack of channel capacity, but because of the priority level of the talk-group that they choose or were directed to communicate on. The system performed as programmed and the lower priority level talk-groups experienced delays to accommodate the communications of the higher priority level talk-groups. This is a training issue not a system capacity issue.

A given user's perception of capacity was also impacted by remote monitoring and the difference between "Fast Start" versus "All Start" personality assigned to a given talk-group when the talk-group was created. How a fleet map is employed on a day-to-day basis can be just as important as how many radio channels one invests in during the system acquisition. The proper training on developing fleet maps and radio usage will mitigate these capacity issues in the future.

On the topic of system acquisition and the costs of adding component parts, it is axiomatic in technologies such as these radio systems that we cannot build (or have the money to build) a system to support "doomsday activities." In other words, we design, build, and train for maximum utility of a system during predictably "busy hour of busy day" scenarios. Few cities buy as many fire trucks or have as many firefighters as could conceivably be required in the event of a wild-fire type conflagration such as the Chicago fire of the 19th century.

It cannot be stressed enough how much more sophisticated, complicated, and feature rich the ARMER system is when compared to the legacy systems it replaced. It is due to this sophistication, complexity, and feature richness that the system performed as well as it did during the bridge collapse incident. However, it deserves equal emphasis to state that the ARMER system's very complexity and sophistication make it far harder to understand for the average 24/7 dispatcher, dispatch supervisor, field responder, or scene commander; and as we hope the previous discussion has demonstrated, it can be actions taken or not taken by dispatchers, field personnel, or system administrators which can have major impacts on system performance.

Recommendation: The Statewide Radio Board (SRB) as overall administrator of the ARMER system should consider implementing mandatory training standards for the several levels of ARMER users.

The significant challenge for bodies charged with governing and administering the ARMER system is to attempt to achieve an adequate balance of technical awareness and competence at the appropriate levels in the user agencies, along with the appropriate level of higher awareness and control vested in system administrator agencies. One of the concepts we have heard discussed, and which we think deserves a thorough examination is the concept of a robust, Web-based training and resource curriculum which could be mandated for dispatchers, dispatch supervisors, and field users of the ARMER system. Such a Web-based system could also be a valuable resource for keeping abreast of system operations, maintenance, configuration, and usage changes.

As conveyed by the individuals that participated in the focus groups, were surveyed or videotaped as a part of this analysis, it is clear that the ARMER radio system performed up to their expectations (and beyond) during the bridge collapse and recovery. The system not only received generally rave reviews from its users, it also fulfilled the hopes of the early planners and those currently participating in the ARMER governance structure in that it removed radio communications from the list of "things that did not work" at this disaster and it actually became a tool which fostered further and better cooperation between responder agencies.

Finally, a lesson to be taken from this event is that the time spent, over a decade, in arduous multi-agency negotiations over system design, acquisition, funding, governance, implementation, and management is a critical component in creating a cohesive core group of persons and agencies who became familiar with and good at planning and understanding each other's needs, and working together with a minimum of "turf battles," and that outcome, in and of itself may be an even more important contribution than the resulting radio system. This lesson should serve as a strong incentive and guide to current and future members of the Statewide Radio Board, the several Regional Radio Boards, and their Regional Advisory Committees as to the importance of their work in developing the procedures and relationships necessary to provide this essential ability to communicate during a major incident.

APPENDIX A: History of Two-way Radio in Minnesota Public Safety

History of Public Safety Radio Communication, Especially in Minnesota

Two-way radio systems first came into common use in public safety shortly after World War II, during which period the technology advanced significantly. In the earliest days, manufacturers had a hard time making systems that would permit acceptable signal reception of high powered dispatch signals by vehicles in the field. So much so that the concept of reliable communications from mobile radios back to dispatchers was secondary, and the concept of effective communications between field radios (mobiles or portables) was even further down the priority list. In fact, it was not uncommon for police calls to be broadcast on commercial AM radio stations to patrolling police cars during that period.

By the late 1960s manufactured were making a great leap in two-way radio technology thanks to the introduction of practical handheld radios (also known as walkie-talkies or portable radios). These advancements were due to the introduction of microprocessors, transistors, and miniaturization, as well as advances in rechargeable storage batteries. Concurrent with improvements in the technology were the Federal Communications Commission's (FCC) reorganization of radio frequencies (also known as channels) into groups of similar users, generally referred to as "radio services," such as the police service, the fire service, and the highway maintenance service. These actions not only organized the usable radio spectrum by type of user agency, but they also provided additional frequencies in higher frequency ranges than had been in widespread use at the time.

Specifically, two-way radio communication in the 1950s tended to be in the low band range between 39 and 46 Megahertz (MHz). Low band is legendary for the up-side advantages of its long signal travel (hundreds of miles), as well as for its down-side potential for interference from distant transmitter on the same (or a very nearby) radio frequency.

Since the use of low band communication proved to be problematic for local and state public safety users (low band was not very amenable to the development of portable radios), manufacturers began producing and the FCC began licensing systems in the Very High Frequency (VHF) spectrum. These systems operated in the 148-174 MHz range, with the vast majority of state and local users licensed in the 150 MHz range.

In Minnesota in the early 1970s, the transition in technology and regulatory action resulted in a number of public agencies operating on low band systems (highway patrol, many fire departments, and a few county sheriffs) and a number operating on VHF systems. With the exploding growth in population throughout this period there were vast increases in the number of public agencies using two-way radio. This growth resulted in a severe shortage of radio frequencies for public agencies to support their operations. In many instances, agencies could not get radio channels and others were required to share heavily congested radio channels with other agencies. And, while the problem was significant in Minnesota (especially in the Twin Cities Metro area), it was far more severe in places like the Chicago, New York, and Los Angeles and other population centers throughout the country.

At the same time, the FCC opened another portion of the radio spectrum for two-way radios in the Ultra High Frequency (UHF) range at 450-512 MHz for local and state government. A relatively small number of UHF channels were made available to local governments nationwide to ease congestion, and even more were made available in a special segment of the UHF band to users in the nation's largest Metro areas, not including the Twin Cities.

Capitalizing on these technological and regulatory advancements, Minnesota state government embarked on a federally funded Police Radio Modernization Plan, which was completed in 1975. Under this plan, the following major outcomes were achieved:

- State, county, and local police radio frequency assignments (although such license assignments are a federal FCC prerogative) were re-aligned (using the inducement of federal funds) so that every county and city law enforcement agency in the state was assigned to operate on VHF channels as their primary radio system, with the exception of four agencies in the core of the Twin Cities Metro area: The police departments for the cities of Minneapolis and St. Paul, and the special jurisdictions of the University of Minnesota and MSP Airport Police departments, which were granted exclusive use of a dozen or more UHF radio channels for their operations.
    - Essentially, this created a "donut and the hole" concept with the "donut" being surrounding VHF law enforcement agencies, and the "hole" being core UHF law enforcement agencies, the Minnesota Highway Patrol (about this time it was re-named state patrol) continued to operate on a low band (42 MHz) statewide radio system. Therefore, to make the state patrol a party to this new VHF regime, all 504 state patrol cars and 10 state patrol dispatch centers were equipped (using the same federal funding source) with VHF radios (mobiles only, in the field) as secondary radios.
    - Concurrently, this police radio modernization process spurred implementation (and funding) of a Minnesota Statewide Emergency Frequency in the VHF band called MNSEF, located at 155.475 MHz. (155.475 MHz had already been set aside and designated by the FCC as a National Law Enforcement Emergency Channel or NLEEC), as well as a UHF equivalent channel called the Metro Emergency Channel at 460.275 MHz repeater output and 465.275 MHz repeater input.
- All two-way radios in county and city law enforcement agencies, statewide, were replaced with either new federally grant funded VHF or UHF radios (both car-mounted mobile radios and handheld portable radios).
    - Importantly, VHF and UHF radios are not compatible. One cannot talk directly to the other. Under this backdrop, this meant that VHF equipped suburban police officers from, for example, Bloomington could not talk to UHF equipped police officers from Minneapolis or St. Paul. Nor

could a VHF (mobile only) equipped state trooper talk to UHF equipped MSP Airport police officers.

- To deal with this shortcoming of the 1975 plan, a somewhat exotic "cross band repeater" was implemented that took VHF traffic on the MNSEF channel and connected it to the UHF Metro Emergency equivalent channel, and vice versa, but it never worked very well, and was certainly not user-friendly in its setup or usage. Later, individual agencies implemented "cross channel patch" capabilities in their own dispatch center's radio control consoles to try and electronically connect these incompatible VHF and UHF emergency radio channels for incidents such as cross jurisdictional pursuits, dignitary motorcades, and the like. But these too proved to be operationally challenging and less than fully effective for a number of reasons.

- Of equal importance is the fact that all of the above coordinating activities were strictly related to law enforcement, with no concurrent federal funding or actions related to the fire-rescue service, highway maintenance, general local government (streets, parks, sewer, transit, etc.), or emergency medical services (EMS).
  - Fortunately (with the exception of the St. Paul Fire Department), all fire departments in Minnesota had been assigned radio channels in the VHF band. (St. Paul Fire was on UHF.) This meant that all fire departments except for St. Paul equipped themselves to use the Minnesota Statewide Fire Mutual Aid Channel at 154.295 MHz.
  - In the EMS world, the FCC did set aside a number of UHF repeater channels for use by EMS, and they were fully implemented in the major Twin Cities EMS operations under the organizational control of two Medical Regional Control Centers (MRCCs), with one being out of Hennepin County Medical Center (HCMC) and the other out of Ramsey County. These MRCC's coordinated which UHF radio frequency would be used by the paramedic crew on a given incident to talk to their medical control authority. But in greater Minnesota, EMS providers continued to operate on a handful of VHF ambulance and hospital radio channels as well as the statewide hospital channel at 155.340 MHz.
  - The only "all-service" VHF channel set aside for inter-agency communications was at 155.370 MHz, which had historically been used as a "point-to-point" channel for one dispatch center to call another (within range), usually sheriff's offices, nationwide. But in the 1990s Minnesota re-purposed 155.370 MHz to be the "Minnesota Incident Management Systems" (or MIMS) channel and authorized any legitimate public agency to operate radios on it under rules adopted by a governing board.

Such was the Minnesota public safety/local government two-way radio world in about 1990. In the 1980s radio vendors began to market a new technology called trunked radio, and while trunked radio systems can certainly be implemented using VHF or UHF radio channels at 150 or 460 MHz, for several reasons they almost always tend to be implemented at 800 MHz. Therefore, the term "800 trunked radio" has become a short-hand way of referring to these systems, but not a very accurate one. Simply put, 800 MHz radio systems do not have to be trunked and trunked radio systems do not have to be at 800 MHz, but they usually are.

APPENDIX B: Bridge Incident Respondent's Survey

Question 1: Did you personally respond to or have a direct communications role (such as being a dispatcher) in the August 1, 2007, I-35W bridge collapse?

The purpose of this question was to be able to separate responses between those who were at the scene and serving as dispatchers, as opposed to those who were monitoring radio traffic from some other locations.

Yes:	67	(76.1 percent)
No:	21	(23.95 percent)
N/R:	0	(0 percent)

Question 2: If you were not a responder, or you did not have a direct role as a dispatcher in the bridge collapse, did you monitor bridge related activities on the radio system? Please provide comments below if your answer is 'yes'. Specifically, how and from where did you monitor radio activity?

The purpose of this question is to clarify that those who were not responders to the scene and try to ascertain where they were monitoring from (geographically) and whether it was via a subscribed radio or a scanner.

Yes, I actively monitored even though I did not have a direct role. (Details below please)	28	(84.8 percent)
No, even though I was on duty, I did not actively monitor the bridge incident on the radio.	5	(15.2 percent)
How did you monitor and from what geographic area? (See free text responses below)	30	

Detail from responders who provided additional free text replies to Question 2:

- Briefly monitored from time to time. I was acting as the communication center supervisor and was quite busy with other telephone calls, staffing, and assisting other management with equipment/resources.
- Chaska, Excelsior Fire District and then a move up to St. Louis Park Fire. I monitored on my 800 MHz portable and mobile radios.
- Monitored both PTAC talk-groups and Minneapolis Police and Fire talk-groups from MECC.
- I was the senior supervisor on duty in Minneapolis emergency communications at the beginning of the incident.

- Our agency responded to assist but during the incident I was listening as to what resources where needed to better prepare responding personnel.
- I was monitoring for our fire department in case of a request to respond.
- Notified via radio that another supervisor who overheard the MSP radio communications that the I-35W bridge went down over the Mississippi River in Minneapolis.
- Using 800 MHz portable radio in Maple Grove.
- I was MTPD dispatcher on duty at the time in the control center for Metro Transit dispatch downtown Minneapolis, first call came in from MTPD officer who was near the scene when at time of event.
- PTAC1 in Ramsey County.
- Fire dispatcher - monitored fire dispatching activities related to night shift command post needs throughout the night until further day shift recovery efforts continued in the morning.
- Monitored on UMPD and Minneapolis PTAC channels. Was on the north end of the remaining bridge and down below near the river.
- I was the only ambulance service to respond to the northeast side of the bridge collapse. I had front line radio contact with receiving hospitals along with incident command and our dispatch.
- Television news photographer. Shot helicopter aerials of the event on day one.
- As the shift lead at the time of the collapse for HealthEast Medical Transportation I had our dispatch center contact HCMC EMS com center and ask if we maybe of assist to them, they asked us to standby they will call us if needed. We put our crews on stand by.
- Monitored and operated on the two TAC channels being used on the incident scene. Also monitored our main dispatch channel. 10th Avenue bridge.
- Location: Bureau of Criminal Apprehension operations center which has the Minnesota Duty Officer Program. 1430 Maryland Avenue, St. Paul. We relayed and directed requester info to correct talk-groups. Maintained contact with state agencies and forwarded requests from on scene personnel. Handled that activity plus notification and coordination of state agencies and resources for the first four hours until the state emergency operations center became operational.
- The event was monitored by my command post in Brooklyn Center.
- From the Metro Transit control center in downtown Minneapolis, I overheard the first Minneapolis squads arriving on scene on either MNSEF or a PTAC channel - I do not remember which. As a result, we were able to be in the loop as many of our transit squads responded to the scene on their own accord. We were also able to provide more timely support assistance by gathering information on ARMER and not having to bother Minneapolis communications with questions.

- Not on an 800 system.
- I was in the Hennepin County EOC and then Minneapolis.
- Responded to the county dispatch center and monitored from there. Had no other direct role except to communicate with local law enforcement to plan for sending assistance if requested.
- Minneapolis 311 contact center was open and provided not only relief to the Minneapolis 9-1-1 system, but provided information to customers (victims, relations, and affected parties) on August 1 and after. Communication sources were limited and primarily from reporting news agencies. Minneapolis 311 is setup at the third precinct of the Minneapolis Police Department.
- As the Emergency Management Director for Anoka County I monitored from my emergency operations center located in the City of Anoka.
- District supervisor in St. Cloud area with 800 MHz radio Comm link through Camp Ripley. Monitored event and attempted to contact one of the Metro District Supervisors on DNR TAC to determine outside personnel and watercraft response needed. Unable to get through on that channel due to its lower priority setting.
- As communications manager for my hospital and ambulance service (and being on my day off), I monitored from Mayer until I felt confident that our service would not be involved and I did not need to return to the hospital to coordinate our emergency plan.
- Dispatched on Metro Transit street operations talk-group. Monitored mutual aid PTAC talk-groups. Geographic area: downtown Minneapolis.
- I responded to the collapse site along with over 80 percent of UMPD. Our property lies under the north end of the bridge and we were most familiar with this area. We also have property on the south end, west bank office building, and are very familiar with this area from our patrols. I used my portable radio and we had our mobile command post on the north end of the bridge.

Question 3: If you were a responder to the bridge collapse scene or had other responder duties associated with the bridge collapse, please select below the one response that best describes your role as a responder to the scene.

The purpose of this question is to determine whether or not the type of agency the responder was with had any bearing on that user's experiences or perceptions of the system's performance.

Law enforcement officer	18	(29.5 percent)
Metro Transit user	3	(4.9 percent)
Fire/rescue responder	5	(8.2 percent)
EMS responder	14	(23.0 percent)
Mn/DOT responder	1	(1.6 percent)

Minneapolis Public Works responder	0	(0 percent)
Federal agency responder	1	(1.6 percent)
Water patrol/rescue responder	2	(3.3 percent)
News media	1	(1.6 percent)
Emergency Management-Emergency Preparedness responder	8	(13.1 percent)
Other (details below)	17	(19.3 percent)

Detail from Question 3 "other" free text responses:

- Police channel dispatcher.
- Assist with move up support for fire agencies.
- On call administrator for NMAS.
- US Coast Guard, but brought my radio from Edina Police for communications.
- Ambulance dispatcher.
- HCMC dispatcher.
- Police dispatcher for Metro Transit Police Department.
- On scene incident commander.
- Medical director.
- Stand-by for inter faculty transport.
- Dispatcher.
- Dispatcher for EMS.
- Cert volunteer.
- Provided info to responding agencies include: Minneapolis Police Department, Fire, Public Works, Emergency Management, State DOT, Patrol, etc.
- Security manager.
- Public health emergency preparedness at family assistance center.
- U of M Police Department dispatcher.

Question 4: Dispatchers only: If your role during the bridge collapse was that of an agency dispatcher, please tell us which agency and your role at that dispatch agency.

The purpose of this question was to clarify the responses based on level of involvement in the incident. (Agencies with no responses not presented.)

Minneapolis Emergency Communications Center (the Minneapolis 9-1-1 and police and fire dispatch center)	7	(25.9 percent)
State Patrol Communications	2	(7.4 percent)
U of M Police Department	2	(7.4 percent)
Mn/DOT Communications	1	(3.7 percent)
Metro Transit Communications	3	(11.1 percent)
HCMC EMS Communications	2	(7.4 percent)
North Memorial EMS Communications	3	(11.1 percent)
Richfield Police Department/Fire Department Communications	1	(3.7 percent)
Edina Police Department/Fire Department Communications	1	(3.7 percent)
Other, describe below	5	(18.5 percent)

Question 5: In order to assess how well the ARMER radio system met user needs during the bridge collapse incident, we need your opinions. We are interested in both technical (How did the ARMER system work electronically?) and operational (How well was the ARMER system used?) perspectives. The first question is: When you wanted to speak, were you regularly granted electronic access to the system? (As opposed to receiving a "system busy" tone notification.)

The purpose of this question was to assess the degree to which the system met the requirements for electronic access to the system.

Yes, I could regularly access the system	39	(54.9 percent)
Yes, I could regularly access the system, but with an occasional delay	20	(28.2 percent)
No, I received too many "system busy" tones for too long	8	(11.3 percent)
I cannot recall	4	(5.6 percent)

The detail for the 23 free text comments on Question 5 is as follows:

- Dispatcher radio consoles have priority over all squad/portable radios except those in emergency mode.
- I believe there were too many busy tones. The system did hold up, but I believe if it had been larger scale, there would/may have been a communications break down.

- There were a number of transmissions that sounded like several people on the air at once not being blocked because someone was already talking.

- Our dispatchers have priority on our talk-groups - they can talk over the responders when necessary.

- Very occasional.

- We were given an assignment very close to the command post for a road closing. I never got on the radio.

- No "system busy" tones, but the "in use" "bonk" was more common...to me, this was more about the users, as opposed to the ARMER system.

- Monitored the incident only, never made any attempt to speak.

- By the time the night shift had taken over it was to monitor and facilitate requests as needed for the fire command post and MFD incident commander in charge. All rescue and recovery efforts had ceased till daylight. We continued to receive outside agency offers for assistance and relayed such requests to the command post or the incident commander for coordination for the morning efforts throughout the night.

- It was very hard to get in and talk with receiving hospitals, MRCC, and incident command. There were several times that we would try to contact someone and where unable to. We stopped trying to contact the hospitals/MRCC and brought patients to HCMC without them knowing we were coming. We simply could not get through.

- We do not transmit. (news media)

- We had some busy signals in the first 45 minutes. Mostly due to priority usage by EMS, fire, and police responders on the system. We in Mn/DOT would like a higher priority on the system. But I believe our communications area is working on that.

- On-scene communication was not affected, considering the amount of radio traffic. We did receive an occasional system busy due to the amount of initial on-scene radio traffic.

- Perfect!!!

- I received a busy signal two or three times during the entire event. I thought the radio system worked very well.

- I think there were not many system busy tones if I recall.

- Because Minneapolis Fire did not have the capabilities to switch to a common tactical channel without some serious patching we never were able to talk with them on a common channel. We did use ARMER to talk with our own dispatch system without incident. The fear was that as overwhelmed as it appeared MPLS Dispatchers were, if there was an attempted patch and it did not work we could lose what communications we had.

- I stayed off the system because of the congestion on the EMSTAC; I communicated with the EMS branch command via telephone, SMS, or through WMRCC.
- I was the incident commander for the sheriff's office response. I did not have any problem ever getting electronic access at any time during the first critical hours.
- As stated above, I wished to communicate on DNR law enforcement tactical channel direct to on-scene DNR law enforcement supervisor to ascertain personnel needs, and was unable because of "system busy" tones. I tried cell phone too without luck until I finally got through with federal gets card.
- Still very confusing as a UMPD officer. We have our own channel to speak on. There was MPD PCT 1 and PCT 2 that we were also communicating on and eventually a PTAC channel was implemented. Unfortunately, our administration and other leadership was not monitoring this system but we could not keep track of/scan all the stations at the same time (not to mention complete the recovery efforts that were necessary at the time).
- I worked near our command post and was regularly updated by those working with me (I was in a command position), I rarely needed to actually talk on my radio.

Question 6: The next question deals with the ARMER system's usage congestion as opposed to electronic capacity. Here is the question: On the radio talk-groups which you used during the incident, were those talk-groups so heavily used that you had a hard time getting on the air with important radio traffic? (We are not talking about you being electronically denied system access...we are talking about you not being able to talk because others were talking whenever you wanted to talk.)

The purpose of this question is to get at the other side of the capacity discussion, that of 'human factor' congestion, as well as the appropriateness of talk-group design and usage.

Yes, I had a hard time getting air time to say important things due to the talk-group(s) I was using being so heavily used	21	(29.6 percent)
No, I was generally able to get air time to say important things I needed to say	48	(67.6 percent)
I cannot recall	2	(2.8 percent)

The free text responses for Question 6 are as follows:

- Especially in the opening minutes as units began arriving the usage level was high and we/I had trouble getting time to air the PTAC channels that different aspect of the rescue effort.
- This was one of the most frustrating parts of the handling of the initial incident.
- Early on, it was a little confusing, but once we got sorted out, and got organized, things got a lot better.

- Again, never used the radio. Just monitored.
- There was a lot of chatter on the radio at times due to multiple units talking at once where I could not transmit immediately.
- Monitored the incident only.
- I was mainly on police main and monitor MPPD channels.
- Our talk-groups worked very well.
- Only problem certain agency fleet maps did not have duty officer nor BCA talk-groups programmed, they are automatic and need no direct approval.
- We went through outer PSAPs and talk-groups not immediately involved in the incident to get resources we needed that were outside the system.
- The EMS TAC channel was busy; we realize we should have moved divisions or areas to another channel at times.
- I had advised Minneapolis that state patrol was going to patch with a "P" TAC and have responding units go to that TAC. I quickly found out need to split off responding units we did and the problem was solved. This problem only lasted a few minutes.
- My personal on-scene work consisted of security after the actual response phase and presidential security detail. At that time, the PTAC channels that were setup proved to be adequate and not overly burdened. I scanned three of them I think and they were setup well.
- See above. In the days that followed the radios worked fine.

Question 7: When you needed to use the ARMER system on August 1, 2007, did it provide the audio clarity that your situation required? In other words do you feel you were clearly heard, and did you hear others clearly?

The purpose of this question is to delve into the issues related to the clarity of the digital audio signal.

Yes	75	(94.9 percent)
No	1	(1.3 percent)
Cannot recall	3	(3.8 percent)

Free text responses to Question 7:

- The majority of time yes.
- I do believe there were some garbled messages, but for the most part it worked pretty well.

- There was some tailgating noted...conversation after we un-keyed...and some distorted communications occasionally.
- Could hear the traffic very well.
- From my position the radio system worked flawlessly, on the PTAC designated for river operation (water).
- Yes, the St. Paul Police Department did not have 800MHz and was cross-patched. The clarity of their transmissions was not as clear.
- Outstanding!
- I could monitor clearly.

Question 8: When you used the ARMER system on August 1, 2007, did you decide on your own what talk-group (or channel) to use, or were you told by somebody else which talk-group (or channel) to use?

The purpose of this question was to attempt to develop an understanding of whether users were making their own ad hoc decisions on what talk-groups to use, or were dispatchers or higher scene commanders advising them on what talk-groups to use.

I decided on my own	22	(31 percent)
I was directed by somebody else (specify below who told you)	44	(62 percent)
I cannot recall	5	(7 percent)

The free-text responses to Question 8 were as follows:

- Separate channel was setup for police prior to my arrival in the center.
- HCMC had my ambulances responding use. I continued operations on ALS during the incident providing mutual aid for HCMC, and continuing North Memorials normal operation.
- I held a main Minneapolis talk-group but the action of moving people to PTAC-1 was per an SOP for water emergencies so that Hennepin County water patrol could be part of action on the river.
- I was directed to an ETAC channel by the EMS branch director.
- HCMC Ambulance dispatch.
- SOP for EMS.
- I directed the talk-group usage that the dispatchers utilized.
- Hennepin County dispatch.

- Minneapolis dispatch advised what channels were being used.
- HCMC EMS communications.
- EMS west MRCC/supervisor.
- Incident command.
- Incident command.
- HCMC communications assigned the two talk-groups and told other responders what talk-groups to use while at the incident.
- Hennepin EMS dispatch.
- Boss.
- HCSO dispatch.
- Monitored the system only, but found active talk-groups by trial and error.
- I stayed on my Metro Transit Police main channel.
- Deputy Fire Chief provided guidance.
- MFD incident commander and MPD incident commander for police activities to be coordinated with MFD incident activities.
- EMS branch command.
- I used both UMPD and the PTAC.
- Dispatch (North Memorial).
- HCMC EMS Comm advised us.
- Our dispatch staff.
- As the supervisor I made that decision. But it was already in our protocol, so even if a supervisor had not been present it would have happened the same way.
- We operated on two TAC channels throughout the incident. TAC channel use was established by command.
- Ramsey County communications center assigned us to pool channels.
- We have three consolettes and a portable we figured it out ourselves, used the SRB standards for interop.

- U of M communications relaying for MPLS communications.
- MFD and Edina.
- Management from the scene.
- HCMC communications center.
- Dispatch.
- HCMC dispatch.
- HCMC dispatch/WMMRCC.
- HCSO communications center.
- This was predetermined for emergencies. EM's used the SEMTAC channel. Worked well to communicate with surrounding county EMS, however, we did not have good communication with the scene initially which we thought we would/should have.
- Based on training and knowledge of the system…I knew where to go to get information and provide information during the response.
- UMPD PSAP supervisor.
- MECC assigned a PTAC to police operations.
- Unfortunately, we were told to change channels multiple times by dispatchers and supervisors from UMPD, MPD, MECC, etc.

Question 9: Tell us which talk-group(s) or conventional radio channels you used during the bridge collapse in order of how much you used them.

The intended purpose of this question was to assess which talk-groups were used the most. However, the choices presented failed to ask for names of talk-groups, so the results are not meaningful, and are not presented.

Question 10: Do you feel that the training you received before August 1, 2007, on how to use the ARMER 800 MHz trunked radio system adequately prepared you for how to use it on August 1, 2007?

Yes	69	(88.5 percent)
No	9	(11.5 percent)

The free text responses to Question 10, regarding training were as follows:

- I knew how to use the radio and what channels should be used but the system still felt like it was being overwhelmed.
- I wish my dispatchers had taken initiative to utilize information available to more fully understand the radio system as it had been in place in Minneapolis nearly five years.
- Having a standardized list of channels that officers can carry with them.
- Training was good for day to day use. I believe we all need more training on how to use the system most effectively during major emergencies involving many agencies. Who decides which talk-groups? Who links local tactical talk-groups to regional talk-groups in midstream during the emergency? Example: initial responding organization begins operations on their own tactical talk-groups. As the incident evolves it is difficult to change use from the local TAC talk-group to a regional. Command deals with operational issues, who manages talk-group assignment or crosspatches? How is this information communicated during operations?
- I know how to listen in on other channels and talk-groups would not mind a refresher course on the whole system again and patching calls properly. We do not patch calls on a regular basis so easy to forget.
- Classroom in-service training would be good, or online video and test.
- We do not use radios very often so practical hands-on.
- Yes, but then I wrote the state course.
- Our EMS system needs to exercise the use of on-scene divisions and the tactical use of multiple talk-groups.
- I have never had any official training. I have just figured it out on my own or through other officers. I do feel comfortable with the radio.
- Not involved in system yet.
- We should have spent more time figuring out just what talk-groups we were likely to use and how we were going to get there. Fire only had one possible patch to use with mutual aid companies.
- I received training prior and have for reference a two page quick reference guide and for more detailed info the whole PowerPoint from the training.
- It might have been nice to know what was going on with the other agencies in a crisis that large. Paying attention to 'my little world' made it clear what I had to do, but other agencies were working with us as well.
- Definitely not.

Question 11: Now we are interested in how the ARMER system was used, and how effective that usage was. The first question is: In general, do you think that users talked too much, too little, or about the right amount, given the nature and scope of the incident?

The purpose of this question is to assess user perceptions about how the system was used, as opposed to how well it worked.

In general, users talked about the right amount	44	(53.0 percent)
Some users who talked, talked way too much	23	(27.7 percent)
Most users who talked, talked way too much	6	(7.2 percent)
No opinion	10	(12.0 percent)

The free text responses to Question 11 are as follows:

- Some occasions of long transmissions and conflicting with other people attempting to transmit.
- For the scale of the incident, I believe the responders on-scene and dispatching went very well.
- This differed with agency. ETACs were busy but not so busy that we couldn't get on one if needed. Situation was handled well considering response required.
- Many veteran responders reacted noticeably to the scene.
- It was early in the ICS process and EMS branch director/dispatch had unclear roles of who should field traffic at times. EMS branch director was very, very busy.
- It would have been nice to have a talk-group we could go to for a recorded advisory for where to report (where staging was located and other significant information) similar to the NOAA radios where you can go to the "current conditions" frequency to here there recorded message. A lot of chatter trying to find the correct staging area. Dispatchers where continuously answering that question. If we knew ahead of time that response advisories will always be broadcast over "PTAC 4" or whatever, it might take a load off the system initially.
- Only one agency was just over the line talking to one another, so we dropped their talk-group and told them to contact us on the do talk-group, it was bad.
- Although some users talked way too much, it was a complex incident and some people just needed more training on the radios and which talk-groups to use. Eventually it all worked out after the initial few hours when things were controlled better.
- While many officers/firefighters/EMS were attempting to save and recover people (also requesting ambulances, assistance, etc. over the air), multiple authority figures were discussing items over the air (talking way too much) that probably should have been done over cell phones or decided in person by meeting somewhere on-site.
- Considering the incident and associated confusion I would say do not expect perfection.

Question 12: When other users talked on the radio system, did you find the sounds affecting their transmissions (shouting, screaming, background noise, etc.) to be a problem?

The purpose of this question was to assess whether or not some of the background noise audio problems which have been reported elsewhere were a factor here.

Yes, users should have tried harder to control their voices and background noises so others could understand them better	9	(11.3 percent)
No, in general I could hear what I needed to hear just fine	71	(88.8 percent)

The free text responses to Question 12 were:

- The initial scene was beyond loud but even 30 minutes in people were much more able to call out and block or at least minimize the loud noised behind them.
- Some background noise did affect the quality of the transmission.
- It was not too bad but there were several transmissions nearly impossible to translate.
- Background noise seems to be a problem with most radio systems, human error plays a part too!
- Occasionally some background noise made it difficult to understand transmissions, but users would repeat their messages when advised.
- User voices were fine. The use of bone conduction headsets and noise cancelling microphones would have alleviated most of the problems we experienced with background noise.
- At the very beginning, there was a great deal of chaos where radio transmissions were hard to hear between sirens, screams, vehicle horns, etc.

Question 13: Has been eliminated. Due to its invalid construction, the responses were meaningless.

Question 14: Now we are interested in learning how commercial systems like the Nextel "Push to Talk" system was used and how well they worked during the bridge collapse. Please tell us in your own words below if you were able to use any of these commercial systems and how they worked for you.

The purpose of this question was to probe into whether or not it is practical to rely on such commercial systems during major incidents such as this.

There were many free text responses to Question 14. They are as follows:

- I did not use the Nextel system.

- Nextel is a great service however our agency refuses to allow the PTT feature with ambulances or EMS supervisors.
- Failed big time.
- Direct connect worked flawlessly; attempting to make a telephone call with Nextel service failed 50 percent of the time.
- PPT worked part of the time. Texting worked throughout incident.
- State patrol did not use these.
- Did not use.
- I turned off my Nextel because of too much traffic. Sounds unusual, but too many people were calling, had to stick with a portable radio only.
- I used Nextel and it worked well.
- No. The cell phones did not work because the towers were full.
- Several of my colleagues claimed their Nextel direct connect was not working properly. They said they could hear the alert tone but nothing else. In my experience, direct connect, MMS messaging, and e-mail via Nextel were working fine...I was able to communicate with several people this way when the traffic did not warrant radio communications.
- Yes and no, the people who wanted to communicate with use on Nextel were not on the same groups we were.
- Nextel "Push to Talk" worked that evening and throughout the following 20 days.
- No experience with this.
- Nextel's worked good from where we were in Ramsey County, but we were not directly involved.
- My Nextel Push-to-Talk was intermittent and I was frequently unable to make a regular telephone call.
- My use was limited during the night shift if I needed to talk on the QT with an incident commander. Worked fine, no problems.
- Nextel telephone, worked, but took a few tries. T-mobile worked, but was busy for first several tries.
- Did not use.
- TV news cells were useless. Our two-way radio system was not effective due to ill repair and lack of user training.

- The next Push to Talk system worked pretty well, but when crews tried to call using the regular telephone feature, the system seemed to be busy a lot.
- I/we were trying to use Nextel for Push to Talk and regular telephone use, however, in the hours after the collapse the availability of a signal was very sporadic at the collapse site.
- As for us we lost our telephone lines due to heavy call back/in by staff, we lost cell phone and some Nextel during the incidents first hours.
- We had issues with the Nextel system in the DEOC in terms signal problems.
- We used the 'gets' cards to get landlines. We have Sprint and wireless priority was not available on August 1, 2007.
- I utilized the Push to Talk. I also used occasional cell service.
- Did not use them.
- I felt that this was a problem because folks were communicating on Nextel and not the 800 system. This made responder accountability difficult.
- Nextel Push to Talk was great, never plan to use cellular. But did request Sprint/Nextel and Verizon to jack the towers up 45 minutes after the collapse.
- Used it to speak with our EMS supervisor/manager for a short amount of time. No problems.
- Did not work well. I believe too many users on the system at one time, especially in the beginning stages of the collapse.
- I was able to get text messages and Nextel. I was not able to get cell phone coverage.
- I did not use this.
- I did not use Nextel.
- I used Nextel and Nextel cell phone. The cell phone system did not work some of the time.
- Sorry do not recall.
- Nextel direct connect worked ok. But there was way too much operational business on these telephones that should be on a talk-group.
- Nextel telephone service was practically non-existent due to the system being busy. PTT was the same.
- We used Nextel on this date for our communications and since have abandoned this type of transmission since it was unreliable during the bridge collapse.

- Cell service was spotty as lines were being sucked up. Nextel direct connect usually worked but many were not on the Nextel system or their direct connect numbers were not readily available if not already entered in your telephone.
- Personal cell phone (AT&T) - we were able to make and receive calls under the eastern end of the 10th street bridge, even though others nearby could not. This was approximately one hour after the collapse.
- Cell phone use was up immediately after notification from 6:00p.m. to a short time later. Then coverage was very limited and sketchy. We use the Nextel cell phone device for management. All Minneapolis 311 management was on premise during the emergency and no need to use within our organization. Push to Talk was not used to attempt communication with other resources.
- I used Nextel direct connect as much as the ARMER and never had a problem getting on the air. I had limited cell phone use however.
- I was not a user of the Nextel "Push to Talk," but a number of individuals I was working with were using them and I know it worked well for them. My issue with that though, is that they used that as their form of communications, versus the ARMER system (they were more comfortable with the Nextel's) and that made trying to reach them in an uncontrolled scene extremely difficult and dangerous. I advise using one system only unless there is system failure.
- We mostly switched from Nextel to Pocket PC for key staff a few years ago. At the time of the purchase of the Pocket PCS, the Blackberries were not an option and for our response needs the ability to have e-mail has higher priority than the Push to Talk. I did have a gets card and used that the night of the collapse. The use to the 'gets' card on my personal cell phone to make to work calls. I know that the gets card without WPS does not provide priority on the cell phone system but it does on the publicly switched part of the system so those two calls did go through right away.
- Cell phone coverage was problematic. I do not use the Nextel system.
- Cell use (placing a call) was tough maybe one in five times.
- Nextel PTT and text worked better than voice, and we used it a lot.
- No, it would have been nice for each officer at UMPD to be provided with a Nextel for situation especially like this.
- Telephone lines were jammed.
- My Nextel only worked about 15 percent of the time…overloaded system.

Question 15: Based on your experience on August 1, 2007, during the bridge collapse as a responder or other user, or as one who monitored the system during the incident, please rate the ARMER system's overall performance.

Statement: "The ARMER trunked system performed very well during the I-35W bridge collapse incident on August 1, 2007, and the several weeks of recovery thereafter."

Agree strongly with this statement	60	(68.2 percent)
Somewhat agree with this statement	24	(27.3 percent)
	Positive total =	**95.5 percent**
Somewhat disagree with this statement	4	(4.5 percent)
Strongly disagree with this statement	0	(0.0 percent)

The important free text responses to Question 15 were as follows:

- I believe there were too many busy tones on talk-groups that were not directly supporting the bridge scene. And dispatching other emergency calls became more difficult.
- I think more of the PSAP's need to work together for more uniform usage and channel assignment. Also allowing dispatchers to work with the police and fire departments to that during this kind of incident their training is in line with the street training would be beneficial.
- I think overall communication would have been more difficult if we were still using the communication system we used before the upgraded system.
- While monitoring the system, it was unclear which talk-group the overall command was using, or how the operations were distributed among various talk-groups. By trial and error, I was able to hear some of the radio activity.
- Given the scale of the situation, I feel as a dispatcher, that the system was able to handle the large amount of transmissions. There were occasional "bonks," however, that would/should be expected. If this system was still in VHF, I feel the incident would have been unmanageable and total chaos. It was also nice to have unit identification display (example: EMS).
- The system is a winner.
- From my perspective the ARMER system seemed to perform very well. I am glad that we seem to be ahead of the curve here in Minnesota in this area.
- I feel the system worked very well. There can always be room for improvement in the system use, function, and capacity through ongoing training and familiarization as the system continues to grow.
- Better than advertised. Outstanding!
- If radio communication was decreased for only necessary transmissions; listening, receiving, and transmitting information would have flowed better.
- I believe the system worked well considering the magnitude of the incident. The communications between responders worked well especially after channels or talk-groups were assigned for specific purposes.

- I believe our 800 MHz system is robust and provides great redundancy.

- Do not know.

- The ARMER 800 trunked system allowed the responders in the disaster to branch out and have the amount of talk-groups needed to effectively communicate during the incident. I have worked disasters with limited conventional channels and also with the 800 trunked system. There is no comparison. 800 trunked digital offers the necessary available resources and the audio quality is far superior to analog.

  This is based on observation during the rescue phase.

- I think the system worked fine. Any issues seemed to focus around user familiarity with system.

- The system was excellent!! It allowed us to do our job and provide the services we needed during the most critical time. I have commended the performance of the ARMER system in all my emergency management talks.

- I believe the system worked very well and had it not been in place, a number of responding agencies would not have had the excellent communication abilities they had. A key to the continued success though will be continuing to do training on the use of the radios. These radios are much more complex and for those that do not use multiple talk-groups often, trying to switch and scan between multiple talk-groups during a major incident can prove problematic. Users need to be well versed and comfortable with the capabilities they have to utilize them to their full capacity at the time of an event.

- Overall performance of the system was ok, but not the best. State (and not county) should have taken the lead immediately upon realization that the incident was large-scale and needed multiple jurisdiction response. This would clarify communications and enable setup of talk-groups more quickly.

- After initial confusion passed things sorted out well. Radios functioned well.

Question 16: Finally, we are interested in any added comments you would be willing to share with us. Also, if you have other comments or would like to ask a question, you can send it to plinnee@geo-comm.com. Thanks for participating!

Question 16 comments are shown below:

- I believe that ARMER is heads and tails above any VHF system, and it has greatly enhanced communications. Just being able to see radio identifiers made communications much easier from a dispatch standpoint. Keep up the good work.

- I responded as a military reservist with the U.S. Coast Guard, bringing my portable radio from the police department. The coast guard assets only have marine radio, not the 800. After checking in at the river command, I was told the operations were on one of the PTAC talk-groups and was told to use my police radio on the coast guard boat. Over the next couple weeks portable 800MHz radios were handed out by Hennepin Sheriff's Office to boat crews and this worked well. Again none of the CG boats that responded from around the region had 800MHz radios, just marine radios.

- I believe the overall response to the collapse went well. The ARMER system was a great tool. I think it could have been used more effectively, however. Not having been at the scene, all I can go by is what I heard.
- Helicopters created the only real noise obstacle during the initial response. They made it difficult to understand transmissions.
- System worked well for us.
- The flexibility and capacity of the new system is superior to what was available to us in response to incidents in the past.
- I thought the radio system worked very well. Far better than expected.
- Unified command! Did not happen here. Put away the egos and play in the sandbox as one public safety response!
- State communications (i.e., district state patrol) should take overall comm lead in any large scale incident in order to maintain clear authority and chain of command. This should be spelled out in state law or somewhere so there is no ambiguity over this point. In this incident, which became federalized, there were local agencies that tried to be the "lead" all the time in all things, and I think that the state should be the lead in large incidents. Also, closer adherence to nims (ics) protocols need to be followed.

APPENDIX C: Acronyms and Definitions

800 MHz: A radio, system, or channel that operates in the 794-815 and 839-860 MHz bands. These systems may or may not be trunked radio systems.

"Channel Integrator" (Our term)**:** A fairly new and sophisticated, process/device or system which takes several inbound radio signals from a variety of bands and electronically interconnects them on the "outbound side" to one or more other otherwise incompatible radio channels. Examples: JPS ACU-1000 switch and Ma/Com's "Network First" switch.

Console Patch: Buttons or icons in the dispatcher's radio console that (when properly selected) permit the ability to "patch" or connect two dissimilar regular radio channels or "trunked radio talk-group" together for a specific conversation. (Example: Patching the VHF fire channel to the UHF street department channel.)

Cross Band Repeater: A single device which receives inbound radio traffic on one channel in one band (say MNSEF on VHF at 155.475 MHz) and rebroadcasts it out on another channel in another band (say NPSPAC interop. channel 1 at 866.0125 MHz) and vice-versa.

Digital and Analog: The methods of modulating a radio signal as it travels through the air. Example: Digital signals are the speaker's words turned into a series of 1's and 0's, which are then transmitted through the air, received at the other end, and then reconstituted back into the audio sounds of the speaker's words. Analog signals are the speaker's words formed into wave forms and the wave forms are then sent through the air and can be output through a loudspeaker at the receiving end. Generally, analog wave forms require a wider radio channel bandwidth than a digital transmission carrying the same sound, but digitally.

Encryption: In digital radio systems, all radio transmissions are "digitized" (broken down into a formatted series of 1'os and 0's according to some logic mutually known to all radios on that system) at a minimal, standards based level. In an "encrypted" system, these digital bits are re-coded once again based on a secret code known only to the radios within the system that have been programmed with that same secret code. In older analog radio systems, if encryption was employed, analog voice sounds were digitized, and then sent over the analog channel as an analog wave form to the distant radio, which had to have the similar decryption program in it to unscramble what the transmitting radio sent. This technique dramatically reduced the effective range of the otherwise analog signal, whereas with modern encryption employed over already digital systems, there is no degradation in signal quality or range.

Hard Patch: A system whereby a dedicated radio is installed to take what it hears and always patch it over to another radio system channel or talk-group, and (sometimes) vice-versa. (Example: The street department's UHF radio channel is "hard patched" to a talk-group in the police department's trunked radio system which could be called "streets.")

Low Band: A system or channel that operates in the 39-45 MHz band.

Microwave: A "point to point" radio system that transmits signals (often data) from one fixed point (microwave dish) direct, in a line of sight mode, to another fixed point. Often microwave is implemented to "bypass" expensive, monthly recurring costs for "data lines" leased from the telephone company.

Nextel Re-banding: An FCC mandated process (begun in about 2005 and lasting several years in several "waves") under which numerous public safety licensees operating radio systems in the approximately 821 and 866 MHz were relocated (at Nextel's expense) on the frequency spectrum to a lower spot (but still within 800 MHz), so as to create one contiguous segment of the spectrum for such public safety licensees as well as to create a buffer zone between public safety frequencies and Nextel frequencies. Due to the lack of such a buffer zone, there had been numerous instances of harmful interference between Nextel systems and public safety 800 MHz systems.

"NPSPAC": A radio, system, or channel that operates in the 800-815 and 845-860 MHz bands, (National Public Safety Planning Advisory Committee), formerly sub-group of 800 MHz channels set aside from the bulk of earlier allocated public safety 800 MHz channels. NPSPAC channels also operate under more stringent FCC rules regarding power output by base stations, so as to permit more channel re-use across a geographic area such as a state.

Radio Extender/Vehicular Repeater: The use of a handheld portable radio to talk to the vehicle which the operator is associated with, and then the vehicle radio re-broadcasts the communication into the main radio system, and vice-versa. The portable is usually on a different radio band than the main vehicle radio to which it is connected back in the vehicle. AKA Pac R/T, "Pack Rat," or Vehicular Repeater.

Repeater: A base transmitter/receiver that exists for the purpose of receiving inbound radio traffic on one channel in a band and re-broadcasting it out at base station power on a companion channel in that same band. Example: A VHF repeated channel has field radios talking in on a channel like 156.015 MHz and the base repeater re-broadcasting the signal back out on 155.79 MHz, to which all radios on that channel are selected for hearing the repeater output.

Satellite (or voting) Receiver System: A set (more than one) of receive-only devices placed out in the field at various locations to pick up weaker inbound radio signals and bring them into the "headend" via telephone lines, microwave, or other means to present them to the dispatcher and/or to the repeater to be re-broadcast out.

Simulcast: The process of having a radio signal transmitted simultaneously from multiple transmitters in different locations so as to increase the area over which that radio signal can be heard, as well as the chances of that radio signal effectively penetrating dense buildings.

Talk-group: A selection on a trunked radio's "channel selector" switch which defines a grouping of persons, users, agencies, or radios as a place for them to "meet and talk" via radio. Example: "Police Dispatch South" talk-group would be where all "dispatchable" police units in an agency's "south district" would monitor to hear calls dispatched and responded to. Some refer to talk-groups as "virtual channels" in that they only really exist in the radio system when they need to be used, and the rest of the time they only exist on paper, or in a series of instructions programmed into the trunked radios and system.

Trunked: A computer managed radio system with multiple radio channels. For each transmission, the computer assigns a channel to the participants for the duration of that transaction.

UHF: A system or channel in the Ultra High Frequency range around 450-460 MHz.

VHF: A radio, radio system, or channel that operates in the Very High Frequency band around 150 MHz. If your FCC license says something like 155.250 MHz that is a VHF channel.

APPENDIX D: Primer on Trunked Radio

Understanding Trunked Radio Systems

*Reprinted from **"Ick! I Hate Technical Stuff"**, © Professional Pride, 1998, By Paul D. Linnee, ENP*

One of the latest developments in the two-way radio world is something called TRUNKED RADIO or TRUNKING. For some reason, trunked radio has been a difficult concept for lots of folks to get their hands around. We'll try here to explain the basic concepts of trunked radio in a fashion that (we hope) will enable you to be conversant about a topic that is almost certain to impact your system in the next 10-20 years, if it hasn't already.

First of all, ***trunking in itself, does not necessarily mean 800 MHz*.** The fact is that trunking is a method of efficiently using and re-using several radio channels that could be done (at least in theory) in any of the frequency bands available for land-mobile communications such as VHF, UHF, 700 MHz etc. However, the reality is that for a trunked system to work properly, it needs at least a handful (usually 5 or more) of relatively adjacent **pairs of radio frequencies**. We say "pairs of radio frequencies" because a trunked system is always "repeated". Repeated means that the talk path goes to and through a device called a REPEATER (much more on this later) and it needs one frequency for the transmissions headed to the repeater and another frequency for the transmissions coming out of the repeater. Therefore, each CHANNEL consists of two FREQUENCIES, one inbound and one outbound from the repeater. So, to repeat (no pun intended), a trunked system needs several pairs of frequencies (channels) and about the only place in the usable spectrum left where you can find relatively clean (free of interference) pairs of frequencies is in the 700 and 800 MHz. band. That's why almost all of the trunked systems you'll hear about for the foreseeable future will be at 700/800 MHz. *(Yes, it is true that there are VHF {150 MHz.} trunked systems in use. One place is the entire State of South Dakota, but they could pull it off there due to the fact there were very few VHF licensees in place and they could come up with an adequate number of "clean" channel pairs.*

Now that we've established that "trunked" doesn't *necessarily* mean 800 MHz, but that almost all trunked systems are 800 MHz trunked systems (have we got you confused, yet?), let's try and get a handle on how trunking works. The best way I've found to understand this is to make a comparison between simple two way radio (non-trunked) and simple telephone systems. On day one, when Alexander Graham Bell invented telephone, he ran one pair of copper wires from Place A to Place B. Over these two wires he sent voltage which turned into voice at the other end. This is a "talk path." On day two, he ran another pair of wires from Place C to Place D. This is another talk path. If the telephone world would have followed this basic concept, each of us today would have as many pairs of wires running from the phone at our house to as many other different places as we could imagine we would ever want to talk to. This would definitely be lots of wires and a real mess. Every time we wanted to talk to somebody, we'd have to go into that pile of wire "spaghetti" and find the pair of wires that went to the place we wanted to call and connect them to our phone. Then we'd have to hope that the party we were calling had also found the pair of wires that came from our house and connected them to their phone. If they had, we could send a ring down those wires, they'd pick up and we could talk.

Needless to say, old Alex figured this problem out real fast. What he did was invent "telephone exchanges". That meant that from every house there was just one pair of wires running to a central place. At that central place (you've all seen pictures of old telephone company switchboards and operators), then we'd ring the operator, who would plug into our pair of wires and ask us who we wanted to talk to. We'd tell her and then shed run a "patch cord" from the plug representing our pair of wires to the plug representing the pair of wires that went to the place we were calling. Then she'd put a ring on those wires and the phone would ring at the desired place. If somebody answered, we'd talk. When we were done, we'd hang up and the operator would get an indication of that and remove that patch cord and free up that temporary connection between the two of us.

OK, here's how the analogy works: The first example of a pair of wires running to every place we might want to call is exactly like simple non-trunked two way radio. The only difference is that instead of dealing with wires we are dealing with specific radio frequencies or pairs of frequencies that make up radio channels. Imagine CB radio. If you want to talk to me on CB Channel 14, both you and I have to have CB radios. They must both be turned on. They must both be switched to the same "pair of wires" (channel). Then when you call me, you are the only person who can be talking on Channel 14 at that instant and if I hear you, I answer you. Nobody else in our geographic area (say 10 miles in diameter) can be using that channel at the same time. If they do, we end up in a party line sort of situation, which is what CB is. Now jump to public safety radio. Let's say your agency has a 4 channel radio system with 4 channel radios in all the cars and trucks. If the dispatcher wants to talk to Car 54, the dispatcher must know which channel (pair of wires) Car 54 is tuned to, wait until nobody else is talking on that channel and then call for Car 54. (If you are old enough to remember the TV show **"*Car 54 Where are you?*"** its time to retire!)

You all know what radio scanners are. Imagine you are in TV station's "assignment desk" room in a major metro area. They might have 10 of these scanners mounted on the wall, all humming away. Let's say each scanner has one channel locked in. That means they are monitoring 10 different channels continuously (one on each of 10 scanners). Not all the channels are all talking at the same time (usually). Each channel in each scanner is assigned to a different agency in the same unit of government (1 police, one fire, one street dep't. etc.). All of a sudden, there is a big deal going down in Agency #1 and their channel gets real busy. At the same time, however, none of the other 9 channels are busy at all. The folks at Agency 1 are dying. Their channel is all tied up and they are having a hard time getting any air time for all the important things they need to say, while the other nine are dead silent. If only some of the folks from Agency 1 knew that channel 5 (the sanitation department) was dead silent, they could switch to it, if they even had that channel in their radios. ***This is what trunked radio is all about.***

Let's take the same unit of government and give them a 10 channel trunked radio system. What we do is take all 10 channels and control them by a computer. Then we put all 10 channels in all of the mobile and portable radios of that unit of government. Now, we no longer think in terms of **"*channels*"**. Instead, we think of terms of **"*talk paths*"**, or in trunked radio language, **"*talkgroups*"**. A typical assignment of talkgroups to a unit of government (a city, for example) might look like this:

Talkgroup Designation	***Assigned to***
Police North Patrol	Police
Police South Patrol	Police
Police Tactical	Police
Police Investigative	Police
Police Traffic/Radar	Police
Police Surveillance	Police
Police Car to Car	Police
Police Administration	Police
Police Common	Police
Fire Dispatch	Fire
Fire Command	Fire
Fire Truck to Truck	Fire
Fire Ground Tactical 1	Fire
Fire Ground Tactical 2	Fire
Fire Administrative	Fire
Fire Common	Fire
Sanitation 1	Sanitation
Sanitation 2	Sanitation
Park Maintenance	Park
Park Operations	Park
Sewer Mtce. 1	Sewer
Sewer Mtce. 2	Sewer
Street Mtce. 1	Streets
Street Mtce. 2	Streets
Public Works Common	Public Works
City Administration 1	City Manager
City Administration 2	City Manager
Inspections 1	Building Inspections
Inspections 2	Building Inspections
City Wide Common 1	City wide
City Wide Common 2	City wide
Statewide VHF Emergency (155.475)	Hard patch to MNSEF

Each of the radios owned by the separate agencies are programmed to be able to access only the talkgroups for their agency, plus some or all of the "common" talkgroups (like "city common"). That way, you don't have sewer workers listening in on police surveillance activities, etc. So, for a city that used to have only radio 10 channels, we now have 32 separate talkgroups.

In reality, in a trunked system, all of the radios are actually remote computers first and radios second. Let's take a look at one simple transmission and see how this all works:

• Police Car #1 wants to talk to Police Car #2. #1 knows #2 is monitoring the North Patrol Talkgroup.

• Police #1 selects (via a knob like a channel selector) North Patrol and calls for Police #2.

• Police #1's radio (computer) sends a split second command to the central system computer saying:

- I am Police #1

- I am authorized to access the North Patrol talkgroup

- I want to talk on the North Patrol talkgroup

- Please take a channel (pair of frequencies) from your set of 10 stored channels and set it up to support the following communication between me and everyone else on North Patrol.

• The central computer hears all of this and picks one of the 10 channels in its bank (6) and then:

- Sends a command out to all radios monitoring the North Patrol Talkgroup

- Tells all those radios to tune to channel 6 from the 10 channels the system has.

- Sends a signal back to Car #1 which tells car one it is OK to talk. (*)

• Car #1 talks and everyone monitoring the North Patrol Talkgroup hears Car #1, especially Car #2.

• Car #2 goes to answer, and the whole process is repeated.

(*) Car 1 isn't actually told that it is OK to talk. In reality, Car 1 always assumes that it is OK to talk unless the computer tells her radio that no channels are available on which to set up a talk path for that talkgroup at that instant. In that case, Car #1's radio would beep when she pressed the talk button, with the beep indicating that no talk path is available. This is great, because it means that several users will no longer be permitted to talk at the exact same instant (A dispatcher may never again have to say, ***"Two cars calling, try again!"****). Further, no user will think they got through when they didn't actually get through. Another neat side benefit of trunked systems is that (in order to work and be able to identify each user's radio) each radio is assigned its own ID number. This is really just like ANI (Automatic Number Identification) in an E9-1-1 system. It means that every time a radio talks, its ID number can be displayed for the dispatcher and the other receiving radios. That ID number can be listed in a database and can automatically cause for a plain English display to be shown saying not "RADIO 123344", but "CHIEF SMITH" when the Chief talks. This could be the end to those occasionally gross and inappropriate (but unidentified) comments (or other noises) that some of our fine and professional field personnel find it necessary to make now and then. Further, it also creates the ability to establish a "private call" whereby a properly equipped radio (one with a touch tone pad on it like a phone) can "dial up" the radio number of the party she wants to talk to and then establish a private talk path between her and the other party for the duration of that chat. This would seem to be ideal for Supervisors to use to communicate with an errant subordinate or one needing guidance, without risking everyone else hearing the counseling or other advice being given.*

A final neat benefit of trunked systems is that they are, by definition, much harder to listen to from scanners. In a conventional radio system, if two detectives on a surveillance are saying some really juicy stuff, all on one channel all the time, the scanner buff (or bad guy or "newsie") need only lock in that one channel and (provided they are within range) listen to their heart's content. In a plain (non digital) trunked system, that same buff would have to listen to all 10 channels of our 10 channel trunked system all of the time in hopes of picking up snatches of what the two detectives are saying, because every time they are talking, the computer is assigning them a different one of the 10 channels for their talk path. So, in order to hope to hear them, they'd have to monitor all 10. But, in so doing, they'd have to listen to and wade through all of the other talk going on in the system and, by doing this to pick out our detectives, they'd certainly miss much of what the detectives are saying.

In trunked system design, the key is to have enough channels (pairs of frequencies) serving the trunked system users (regardless how many talkgroups there may be) so that there are very few, if any, occasions where the user's radio beeps to indicate inability to provide a talk path to that user. It is often the case that the number of channels necessary to support a given agency's communications on a trunked system can be as few as 25% or less than they would need for the same level of communications in a conventional, non-trunked environment. The author is aware of a large metro wide trunked system which will support 25,000 end user radios which used to use over 300 conventional VHF, UHF and 800 MHz. channels and it now does it with about one hundred 800 MHz. channels. Further, through this system, every single user has signal coverage throughout the entire 2,500 square mile metro region and has the ability to inter-communicate with any other user from any other agency or type of agency. ***Now that's INTER-OPERABILITY, folks!***

To sum up trunked radio, the technology came into being as a mechanism for getting better efficiency and utilization out of a very limited number of available radio channels in urban areas. In fact, the FCC now requires that any agency that has more than five 800 MHz channels must implement a trunked radio system, and most 800 and 700 MHz channels will likely be used in trunked systems.

🗁 ***SPECIAL NOTE AND CAUTION:***

There are several vendors of trunked radio systems. In general, these systems are not inclined to be able to talk to each other in a trunked mode. Each vendor uses proprietary computer protocols (just like an IBM PC trying to work with an Apple MAC) so that (for example) a Motorola trunked radio cannot be used in a trunked mode on a (formerly called) Ericsson GE trunked radio system (then called ComNet Ericsson and now called MA/COM), and vice versa.

Perhaps you have heard of something called ***APCO PROJECT 25.*** This is a user based standards setting effort which is intended to entice the radio manufacturers to make radios that will all work to the same minimum standard of trunking protocols so that a radio from one vendor will, in fact, work on a trunked system from another vendor, in a trunked mode. This is being done for the obvious reason of ensuring greater inter-system inter-operability, but also for the important reason of ensuring that a unit of government that buys Vendor A's trunked system on day one, can gain the advantage of competitive bidding for the end user radios by getting bids from more than one vendor as time goes on.

PROJECT 25 has been very controversial and a slow process. Its Phase 1 is complete and several vendors have agreed to the protocol standards in it and are delivering "P25 compatible radios". A Phase 2 is also nearing implementation, and it will involve further refinements and capabilities within an agreed upon set of standards.

1.2 ANALOG vs. DIGITAL RADIO

This won't be nearly as confusing as you might think. (Now that's good news!) That's not to say that it isn't confusing, but it is to say that we who use radios really need to know only a small portion of this gobbledygook.

Here goes: Radio systems can send out radio waves that are either the noise (usually a speaker's voice) transmitted in the form of ***analog*** waves which look like squiggly but flowing lines on a radar screen, or they can send out ***digital*** series of 1's and 0's (that's zero, not the letter O). Digital stuff is very common in our everyday lives. All computer data is digital. All those wonderful voice mail messages we hear are digital. If they weren't, can you imagine all the audio tape those systems would use? Virtually all cell phone systems are now digital.

In digital, there are microprocessors at the transmitting and at the receiving ends. The transmitter microprocessor "looks at" all the words sent to it from the talker's microphone. As it looks at those words, it breaks each word down into a series of 1's and 0's (based on what the word sounds like) so that a simple single word might end up looking like this: **100110001111000110110111001**.

Now the transmitter's microprocessor and the receiver's microprocessor share the same "digital dictionary" so that when the transmitter microprocessor hears the word "STOP" and turns it into "1010101010101", when the receiver microprocessor gets "1010101010101" it can "translate" that into the word "STOP". There are three distinct advantages to digital transmissions:

❶ It takes up less space in the frequency bandwidth to send 1's and 0's (even long series of them) than it takes to send words converted into analog waves. Hence, more digital transmissions can be compressed into a narrow bandwidth space than can analog transmissions. This will eventually permit the FCC (when everyone has gone digital) to slice the usable spectrum into narrower channels than we have today. This means we can get more channels from the same bandwidth than we have today, without them interfering with each other. *(NOTE: Recently, the FCC has resorted to auctioning off frequency bandwidth to commercial users of that bandwidth such as cellular providers, paging companies, etc. These auctions are netting literally billions of dollars for the U.S. Treasury, all of which is earmarked for deficit reduction. So you can see why the FCC and the Feds, in general, would like to get more channels within the finite usable spectrum.... so they can get more money from these auctions. Currently, and likely into the future, public agencies such as public safety are exempt from competing for frequencies at such auctions. Thank goodness for little favors!)*

❷ Digital transmissions are generally of a higher quality throughout all of a given transmitter's range. With analog, the closer the receiver is to the transmitter, the better the radio signal quality. As the receiver gradually gets farther away, the signal gradually deteriorates. You have all heard, ***"Your signal***

is getting weak and scratchy*"** as the receiver of your signal gets farther away. That's analog. At some distance away the signal gets so weak and scratchy that it can no longer be understood. With digital, the receiver will likely be able to hear 100% of the message at 100% quality within 100% of the coverage area of the transmitter. ***This does <u>not</u> mean that digital signals go farther! It does mean that a digital signal will be of a generally higher quality within the same coverage area than an analog signal. It also means that when one begins to get near the outer fringe of a digital transmitter's range, the receiver will "drop off the cliff" and not be able to hear anything at all anymore. All of this is due to the little old 1's and 0's. If the receiver can hear and understand about 98% of the 1's and 0's, it can fully reconstitute them and reproduce the voice from the transmitter, just like the transmitter was next door. To help this, these smart guys have also come up with something called *Error Correction Logarithms* which are capable of taking a set of 1's and 0's which have a few 1's and 0's missing and (using some very heavy duty logic programs) figure out what the missing 1's and 0's *should have been* and insert them.

❸ The last of our advantages for digital is security. Remembering our discussion about how it was harder for a scanner buff to monitor a trunked radio transmission? Well, it was harder but the words (maybe not the words they wanted to hear, but still words) could still be heard clearly over the scanner. With digital, what is going through the air to be picked up by a scanner is no longer words. All the typical, older version scanners would hear are 1's and 0's, and they simply sound like "white noise" or pure static. The only radio receiver which can takes those 1's and 0's and make any sense out them is one with the same exact logic within it as the transmitters and receivers of the digital system, and the permutations of how many different coding schemes can be used here are mind boggling. *(I remember when digital first came out for two way radio in the late 1970's, Motorola had a commercial that described the total number of digital coding schemes available to be a number as great as the number of grains of sand that would be present if you covered all of Chicago with 10 feet of sand! Now that's a rather large number in anyone's book.)*

So, not only has trunking made it harder for scanner buffs to hear, by "going digital" we've made it even harder. This may sound neat, but it does have its downside too. For example, assume your agency has installed a digital system, and the cops in your neighboring jurisdictions have scanners in their cars over which they have always monitored you folks. It has worked out well many times when they heard that chase coming their way and so forth. Well, forget that plan! Their scanners are no smarter than the average scanner buff's so all they will hear is your pretty white noise. Further, it's a good guess that your local major "newsies" will not be at all thrilled when they discover they can't listen to the local cops or fire fighters any more. We've heard of several cases where both trunked and/or digital systems have been installed and the installing agency had to make an arrangement with the local news organizations to let the newsies have a receiver only radio that was a part of that trunked and/or digital system so they could listen to, at least, the main operational and dispatch channels or talkgroups. ***Importantly, however, by late 2003, at least one major scanner manufacturer had introduced an well performing scanner capable of receiving and decoding Project 25 digital trunked radio, and they are relatively affordable, at about $550 each.***

The final issue on digital is that it is not unique to trunked radio. True, we're beginning to see more and more digital trunked systems, but one can use digital transmission on any type of system at any frequency band. Cops have been doing digital UHF and VHF for years, especially in their "scrambled" narcotics and other special channels.