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Proceedings of the Workshop on Performance Criteria for Telecommunication Services Under Earthquake Conditions

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Technical Report MCEER-98-0008

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PREFACE

The FEMA-NIST [1] effort to develop seismic guidelines for lifelines takes a system approach in which performance criteria are to be developed for the system. A paper had been prepared for the 1993 National Earthquake Conference which identified several issues related to establishing performance criteria for communication systems. There is a need to review the issues related to performance criteria and to establish a document that could be used as a basis of discussion by the communication industry stakeholders in the development of performance criteria.

The long-term objective is to establish appropriate seismic performance criteria for the public switched network (PSN), to address the needs of the National Security/Emergency Preparedness (NS/EP) Community, and to develop measures to assess if the criteria are being satisfied.

The goals of the workshop were the following:

- Start the process of establishing seismic performance criteria by identifying critical issues that need to be addressed.
- Explore methods for measuring if the criteria are being satisfied before and after earthquakes.
- Explore additional topics, such as identification of research needs and impact of deregulation of the communications industry.
- Generate a report summarizing the finding of the workshop.

The plan for the workshop was to gather a small working group of telecommunications specialists to review issues related to the performance of communication systems, identify key issues that should be addressed in performance criteria, and suggest measures for evaluating them. Topics were identified and brief issues papers were prepared by participants on the appropriate topics. Papers were distributed prior to the one day workshop where the papers were discussed and a consensus were sought as to key issues, the character of performance criteria, and measures for evaluating performance.

Acknowledgments

The author gratefully acknowledges the workshop participants for sharing their expertise, insightful comments, helpful suggestions, and time that was contributed to prepare the manuscripts and attend the workshop. The participation and contributions of the participants have been vital to the success of the workshop. The support of NCEER which made this workshop possible is also gratefully acknowledged and the support of the John A. Blume Earthquake Engineering Center, Stanford University, in developing and hosting the workshop is acknowledged. The support of the Technical Council on Lifeline Earthquake Engineering through the participation of its members in the workshop is also gratefully acknowledged.

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Workshop Summary

Introduction

The definition of the Public Switch Network (PSN) historically has referred to the wire-based communication system. Since the introduction of the radio-based cellular communications system, these systems have typically been distinguished from the PSN, even though mobile telephone exchanges (MTX) are connected to the PSN.

Issues Discussed in the Course of the Workshop

The following reflect the large diversity of comments made during the workshop. The ordering here does not correspond to that at the workshop. For ease of review issues have been grouped into five categories: establishing performance criteria, financing mitigation, equipment and facilities, congestion, and cellular systems. (Note that items have been reordered. The number after the bullet refers to its original position.)

Issues Related to Establishing Performance Criteria

- Overall system performance criteria based on observed performance measures can probably be established, but it will be difficult or impossible to relate these criteria back into operating procedures, software designs, and equipment specifications that can reasonably assure that the criteria will be satisfied. Ideally, performance criteria should address communications for emergency responders and overall economic impacts of communication disruption.
- Performance criteria based on functional criteria to meet communications needs of critical facilities and emergency responders can probably be established. However, it may be difficult to establish system performance criteria that can be related back to system hardware and software design features that can be changed to satisfy the performance criteria. However, performance criteria can serve as a basis for thinking about system characteristics and operating procedures. From this perspective, it may be useful to establish performance criteria to meet communication needs of critical or other functions. For example, performance measures may be related to the ability of emergency response providers to complete calls or for 911 calls to be made to emergency response providers. Such measures may determine the effectiveness of Government Emergency Telecommunications Service (GETS) or the need for its expansion, or for the need of special services with appropriate premium tariffs.
- The complexity, the high degree of interdependency of telephone network operations, the rapid rate of change of the system and diversity of stakeholders raises questions about whether performance criteria can be meaningfully applied to the network control part of the communications system. The communication system is undergoing unprecedented change. The advances in hardware and software are making major changes in the PSN and in radio-based cellular systems. Some system elements, such as the Internet, are taking on new and

larger roles in communications. Entirely new systems, such as the radio-based direct-satellite system are being introduced. In addition, there have been many new organizations providing communication services and the roles of the organizations are changing as deregulation is implemented. As a result, the communications system as a whole is not well understood, even by the major communication companies. This was illustrated by an incident in which a small telephone company contracted for switching signal services from a small independent company. This contractor was not part of the PSN and not subject to its controls or regulations. A software error in the contractor's switching system disrupted signal service operation. This not only disrupted the small telephone company that contracted for these services, but also disrupted several major telephone carriers.

- The performance of the network under unusual conditions needs to be studied further through the development of detailed case studies. The performance from the wide variety of past and future incidents that occur that affect the communication system may improve the understanding of how these systems will perform after earthquakes. While disruptions of a certain size (a 30 minute disruption of 30,000 customers) must now be reported, a detailed review of the incident that assesses its implications for earthquakes or other system disturbances is currently very limited.
- There is a need for the development of a common language that can be used by both the communication service providers and the users (e.g., the emergency response community, commercial organizations, and representatives of the general public). This language must be understood by service providers and stakeholders and be sufficiently precise so that critical issues can be meaningfully discussed. (Some useful terms are discussed in the paper Measures of Performance for Emergency Response Communications, below.) This is particularly important for the emergency response community. Particularly in areas like California, where specialized supplemental communication systems have been installed, (e.g., a microwave system and satellite system), a language is needed that contains a vocabulary describing the characteristics of the different systems so that the strengths, weaknesses and limitation of each can be understood and assessed. This is also needed by the administrators so that deficiencies can be addressed with appropriate communication system enhancements and/or expansions.

Issues Related to Costs and Financing Mitigation

- Cost-sharing between the service providers, the community, and the Federal Government (because of the impact on gross regional and national product and emergency response) may be the most appropriate and equitable approach to financing earthquake mitigation. One model for such cost-sharing is FEMA's disaster mitigation grants and Project Impact programs. Direct losses to service providers are the cost of repairing or replacing-earthquake damaged facilities and revenue losses; indirect losses are the economic losses to commerce as a result of disrupted communications. Recent studies have shown that in the moderate to large earthquakes experienced to date, indirect losses can exceed direct losses by a factor of two or more. For more damaging expected major and great earthquakes, indirect losses will be even greater. Unlike water systems, communication companies are not municipally owned. Thus, direct losses must be borne by the corporate owners. As a result, the companies make normal business decisions regarding the best way to minimize earthquake losses. However, communication system disruption can impair the post-earthquake emergency response of an entire community and cause significant economic losses to the community that can affect the community and tax revenues. If the community is to impose performance criteria above those deemed appropriate by the service providers, it is not clear how additional costs are to be distributed when there are several communication providers.

- It was observed that if insurance premiums can be tied to conformance to good earthquake practices, as done in the flood insurance program, reduced rates for good design could help drive the adoption of good earthquake practices by service providers.
- While not inexpensive, mitigation and emergency planning historically has proven to be very cost effective for the telephone industry in California earthquakes.

Issues Related to Equipment and Facilities

- The effectiveness of current seismic performance criteria for communications equipment (NEBS) has been demonstrated by the good performance in earthquakes of equipment that conforms to these standards. While NEBS assures the seismic ruggedness of the equipment, there is an additional need to assure that the equipment follows manufacturers recommended installation practices.
- There is a need to periodically upgrade existing standard practices for outside plant, central office, and cell site facilities as new methods that provide improved earthquake performance are developed.
- Central offices in major metropolitan areas have typically been in place for many years. New electronic communication equipment occupies a small fraction of the space of the original electromechanical equipment it replaces. As a result, new equipment is frequently installed in existing central office buildings. This eliminates the large cost of a new structure and the move of the infrastructure to a new location. As a result, new central office equipment is usually installed without structurally upgrading the central office building. Many of the structures were built before modern seismic building codes were developed, so that seismic upgrading of existing central offices should be considered. While seismic upgrading may be expensive, it will usually be a small fraction of the total cost of the equipment housed in the building, and is usually less expensive than building a new seismically resistant facility.
- Several incidents were cited where unintended cuts to communication cables caused significant disruption. While organizations are to maintain route diversity of their cables to enhance system reliability, it is not clear how well route diversity is being implemented by the individual telephone companies. The introduction of many new service providers may give the impression that the large number of providers will provide a high level of route diversity. In reality, many of these providers do not have their own communication lines, but rather lease them from one of the major service providers. In some cases, major service providers may lease lines from each other. Thus, the large number of service providers provides a

false sense of route diversity. It was also noted that information on cable routes may be submitted to the National Communication System by telephone companies under conditions of nondisclosure. There have been cases where several companies utilized the same right-of-way and thus the overall system exhibits poor route diversity. Under the terms of the nondisclosure agreement, however, this vulnerability cannot be disclosed.

- There is a need to add external hookups for emergency power and for water needed to cool emergency generators and communications equipment at central offices. There is a need for standard practices to be developed for emergency power and air conditioning systems to improve their earthquake performance.
- One of the causes of the failure of emergency power has been that power needs have expanded since the installation of the emergency power. As a result, when emergency power is called into service after an earthquake, generators may overheat after being on line for several hours. There is a need to periodically compare emergency power capacity with need.
- It was observed that communication assets and support facilities of emergency response providers are often given poor earthquake protection. Facilities for Public Service Answering Points (PSAP) that link the 911 system to emergency response providers, and to county and local emergency operation centers are often under funded. As a result, even if the PSN functions well, emergency responder needs may not be met due to preventable failures in emergency responder facilities. Commercial, industrial, and university facilities may also experience similar problems. While these facilities are generally not considered part of the PSN, their disruption has the same effect as a failure of the PSN.

Issues Related to Congestion

- In recent earthquakes, the single most important factor affecting communication system performance has been congestion. That is, the increase in communication demands far exceeds design limits. As a result, many callers cannot connect to their central office due to excessive dial-tone delays after an earthquake. Even those callers who can reach their central office are often unable to complete the call. This impairment of service most seriously affects calls requesting emergency services, for example to request medical assistance, report a fire, a severe gas leak, or a downed power line. In the moderate and large earthquakes experienced to date, emergency response resources were generally not exhausted, so that the inability to request service was the limiting factor and prevented service from being provided. In larger events, emergency service resources may become over extended so that a request for service could not be satisfied. The Government Emergency Telecommunications Service (GETS), which is described in one of the papers, has been designed to meet this need. It uses the existing PSN and therefore utilizes the redundancy and demonstrated robustness of the system to provide priority call completion. This system uses different telephone companies, which in turn use different switches to provide some protection from specialized software problems or cyber sabotage. While GETS has been implemented by the major long distance carriers, it is not yet available in all communities.

- Traditionally, one of the most obvious indications of congestion on the PSN was the length of delay in dial tone when a handset was removed from the hook. Today, some switches immediately provide dial tone, even though the call must wait to be serviced by the central office switch. Thus, dial tone delay may no longer be a good indicator of system congestion.
- The use of carriers limiting call duration was discussed as a means for increasing the number of calls during periods of congestion without increase existing physical system capacity. It was noted that this would require legislation for implementation as well as a formal method for initiating such actions. While it was speculated that limiting call duration would increase the number of completed calls, data is not currently publicly available to indicate to what the extent that call volume could be increased. It was noted that the duration of Internet connections has impacted the use pattern of the PSN by significantly lengthening the duration of an average call. An alternative is to consider public broadcast appeals as is done in the electric power industry.
- Many major telephone service providers provide pay-phones with essential line service. In recent years, many pay-phones are provided by individuals or organization using lines leased from major service providers. Many of these pay-phones are multiplexed on to a single line so that essential lines service is not provided. Thus, there is less assurance that pay-phones will be provided with an essential service line.

Issues Related to Cellular Systems

- Facilities that house cell site equipment and mobile telephone exchanges of the cellular telephone system are often structures of convenience, such as apartment or office buildings. The seismic capacity of these buildings may not be consistent with critical communications assets they house.
- Cellular phones have become a back-up communications system for many organizations and a primary system for others. There is a lack of understanding among many users about the reliability of these systems and the dependency of these system on the PSN.

Recommendations

Recommendations Related to Implementation of Good Practices

- It is recommended that well founded seismic equipment standards and that good seismic installation practices be established and applied to equipment of all communication service providers. Communication equipment performance criteria (NEBS requirements) have demonstrated their value by the good earthquake performance of equipment that meet these standards.
- The poor earthquake performance of emergency power and air conditioning systems demonstrates a need for earthquake performance criteria and guidelines for these systems.
- Both wire- and radio-based (cellular and satellite) communication systems are used as fundamental means and emergency communications by various organizations. It is recommended that uniform earthquake performance criteria be established for equipment, equipment installation practices, emergency and backup power requirements for these systems.
- Central offices and other critical communication facilities should be provided with external emergency power and water hookups to facilitate the use of external power and water sources.
- Earthquake emergency planning, including periodic exercises, should be practiced by all communication service providers.
- The NCS's efforts to establish a national, priority access cellular system for National Security/Emergency Preparedness (NS/EP) users is encouraged.

Recommendations Related to Research Needs and Future Developments

- It is recommended that criteria be established for the evaluation, and scheduling of upgrading, of seismic capacity of central offices and other critical communication facilities.
- Telecommunications carriers and the insurance industry should establish a national working group to determine how implementation of best practices could be tied to reduction in insurance premiums.
- A consistent set of criteria should be developed for all segments of the communication industry establishing minimum emergency power requirements. These criteria should include the minimum number of days (e.g. 3 days) that central offices and other critical communication facilities should be capable of running on emergency power without fuel resupply.
- Overall communication system performance criteria based on observed performance measures can probably be established, but they will be difficult or impossible to relate back into procedures, software, and equipment specifications that can reasonably assure that the criteria will be satisfied. The rapid change in technology and the impact of the deregulation of the communications industry further complicate the development of overall system performance

criteria. Performance criteria in the private sector is primarily driven by economics. Because the performance of communication systems can have such a large impact on community emergency response and on community, regional, and even national economic well-being, methods for identifying and paying for implementation of performance criteria beyond corporate needs should be pursued.

- There is a need for detailed case studies of significant system disturbances to maximize learning from such events as earthquakes and other system disturbances. For this purpose, telecommunications carriers should be willing to release to researchers detailed data on earthquake affects (subject to conditions of nondisclosure agreements). Federal agencies (e.g. FEMA, NIST, NCS, NSF) should provide letters of endorsement concerning the importance of such research and the need for detailed data to be released subject to the terms of the nondisclosure agreements.
- Post-earthquake system congestion has been the largest impediment to communications. While the GETS system holds the potential for meeting the communication needs of the emergency response community after earthquakes, there may still be significant commercial disruptions. It is recommended that methods of system operation be explored that will increase system capacity when there is congestion.
- It is recommended that methods for identifying vulnerabilities associated with lack of route diversity within individual service providers and among service providers be developed. Carriers should be informed of these vulnerabilities so that system vulnerabilities can be reduced.
- It is recommended that information on good seismic design and installation practices continued to be documented and disseminated to the communication industry.
- It is recommended that guidelines to improve the earthquake performance of end user communication facilities be developed and disseminated. The types of facilities that need to be addressed include PSAP, EOCs, critical facilities such as communication systems at hospitals, fire departments, and police departments, as well as those at commercial and industrial facilities.

Summary of Earthquake Performance of Communication Systems

by

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Abstract

Communication facilities can be divided into those associated with the central office, outside plant, and the wireless network. In general, central office communication equipment that conforms to the NEBS requirements and is properly anchored has performed well seismically. The earthquake performance of support facilities and equipment, such as HVAC, iron work, battery plants, and emergency generators has been mixed. Outside plant has been damaged from earthquake induced fires and ground deformations across faults and in areas of soil liquefaction and lateral spreading. Communication cables have been damaged when special conveyance structures, such as bridges, have been damaged. Communications have been disrupted when structures that house critical facilities have collapsed. The primary cause of disruption to communications has been from traffic congestion.

Introduction

The following material has been drawn from Chapters 3 through 5 of Technical Council on Lifeline Earthquake Engineering, American Society of Civil Engineers, Monograph No. 10. The material deals with central office facilities, outside plant, and the wireless network. It provides a description of communication system earthquake performance. It does not deal with network control performance issues.

Central Office Facilities

Central office facilities can be divided into communications equipment and support facilities. Table 1 identifies items in each class.

Table 1 Central office communication equipment and support facilities.

Communication Equipment	Support Facilities
Entrance Facilities	Building Structure
Main Distribution Frame	HVAC
Cable Handling System	Backup Generator
Switching Equipment	Fire Suppression System
Transmission Equipment	Water Supply System
DC Power Equipment	AC Power Distribution
	Elevators
	Spares and Back-up Supplies

Earthquake Performance of Entrance Facilities

There is as yet no record of earthquake damage to cable vaults. There have been cases reported of water leaks from to damaged underground water pipeline close to a CO. However, the drainage system inside a cable vault can usually handle this situation. There has been no reported damage to cables inside cable vaults, although cables and splice cases that were not tied to their supports have fallen off of their shelves. There have been cases where the soil back fill around the foundation of a structure has settled as a result of the earthquake and this has damaged conduit and may have damaged cables within the conduit. Soil deformation outside of the structure may cause points along a conduit to extend. It has been observed in some manholes that ties on slack cable prevented the cable from deploying when conduit was deformed.

As a note of caution, inspection in the cable vault, which is usually below ground level, should be conducted only after the vault has been checked for toxic and flammable gases by qualified personnel. The inspection should always be accompanied by an employee of the company responsible for the vault.

Inadequately anchored air dryers can tip over or the air lines can be broken and eventually cause water damage to cables, although this has not yet been observed in an earthquake.

Earthquake Performance of MDFs

The earthquake performance of MDF has been good. In the 1985 Mexico City earthquake some frames has their top restraints shift so that the racks were leaning, but their function was not affected, Figure 1. The flexibility of the MDF base requires the bracing system at the top of the frame to carry large loads. The flexibility of the system, particularly its base anchorage, results in a natural frequency of the frame that is in the high energy part of most earthquakes.

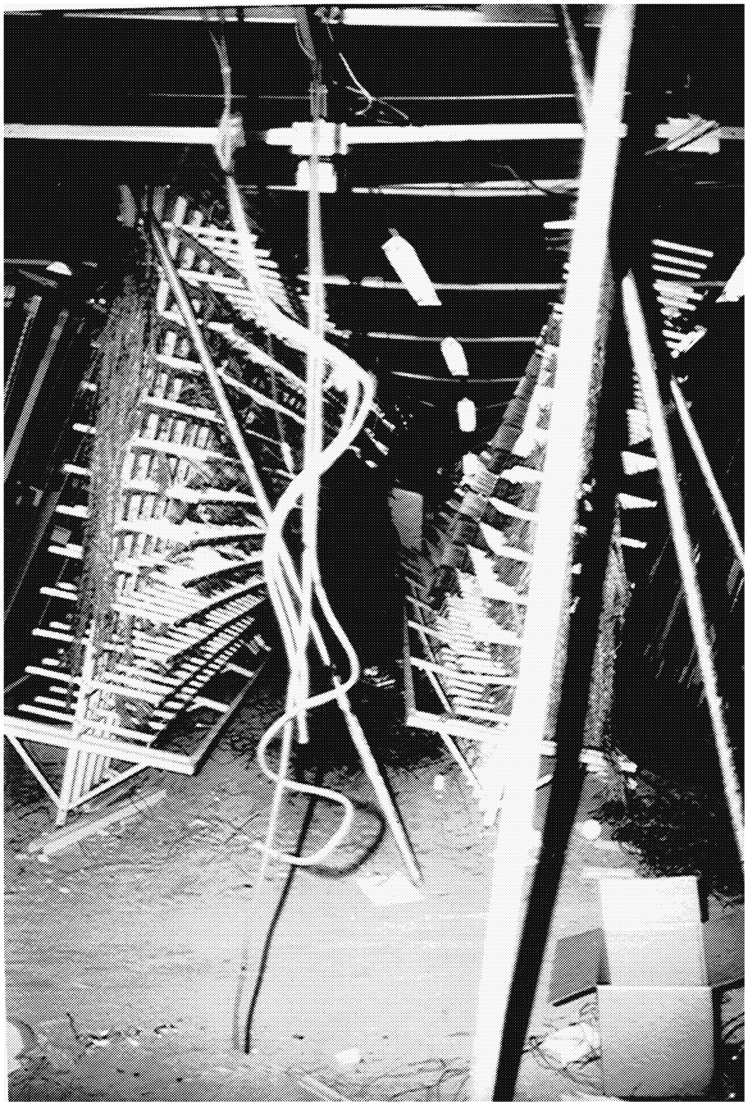

Figure 1 MDFs in the 1985 Mexico City earthquake were forced out of alignment due to flexibility of base anchorage and movement of bracing at the top of the frame.

Earthquake Performance of Cable Handling Systems

There has been a broad range of earthquake damage to cable handling systems, but very little of this damage has resulted in damaged cables or disruption of service. The most common causes of cable handling systems damage are slipping of rack splices at friction clips, racks overloaded with cable, and inadequate lateral bracing.

Cable Racks and Conduits

The most serious case of earthquake damage to a cable handling system severely affected the operation of an important CO. A cable rack impacted another rack, deformed, and caused one of the rungs on the rack to fail. The fractured end of the rung cut through the insulation of a 48 volt DC power cable in the rack and shorted it to ground. The cable insulation was charred due to the heat generated by the short circuit. The over current of the short circuit tripped the power converters at the switch, which disabled all telephone service connected to the switch. After power was restored, critical operations at the CO were transferred to another CO as a precaution.

Cable rack overloading is one of the main contributors to cable handling system failures. In old COs that have seen long service and have been through several changes of equipment, new cables are added on top of existing out-of-service cables and eventually overloading results. Because of the high labor cost and risk of damaging cables in "mining" old cables, that is, removing unused cables, mining is seldom done. Thus, knowledge about the problem does not necessarily yield a solution, particularly when the earthquake risk may be very low.

Some friction clip splices used to join cable rack sections have pulled apart, as indicated in Figure 2. The friction clip splice provides no continuity of axial load or bending moment capacity across the splice. Continuity of the strength of the cable rack is of importance. When a support fails, the cable rack must be able to support itself over the lengthened span between the remaining supports.

Figure 2 Friction clips used to splice cable racks together have pulled out in earthquakes. A positive structural connection is the preferred method of splicing.

Cables in cable racks can fall out of the racks if they are not held in place with tie-wraps. One potential problem associated with cables falling over the edge of the rack is that in areas where the framing system in not braced, movement of the rack may cause the cable to be pinched and damaged if the rack strikes something. In seismic areas, NEBS requires six inch clearance between the framing system and equipment. Old practice allows six to twelve inches clearance of the superstructure from walls, but site conditions could not accommodate these clearances.

Auxiliary Framing Systems

The most catastrophic failures associated with the auxiliary framing system was in the 1971 San Fernando earthquake, where the braces to walls around the periphery of the equipment room failed. As a result the top brace to the tall equipment racks lost its ability to restrain the equipment and all of the equipment in the room tipped over, as shown in Figure 3. In this case the ledgers that anchored the frame to the wall were pulled from the wall or in some cases the auxiliary framing member acted like a battering ram and punched a hole through the wall.

Figure 3 Switching equipment in a CO tipped over when overhead bracing and base anchors failed in a moderate earthquake. The equipment was a total loss and it took several months to replace and install new equipment. It took four days to install temporary lines to provide limited service until regular service could be restored.

There have been cases, where due to the movement of the framing system, wall-mounted electrical conduit was crushed, as shown in Figure 4. In some cases the motion exceeded the clearance to building columns and pounding damaged the framing, Figure 5. Large frame motions have also exceeded the slack provided in cable drops to equipment and this has damaged conductors.

Figure 4 The motion of the framing system, which exceeded 10 inches, crushed electrical conduit mounted on the wall of the equipment room.

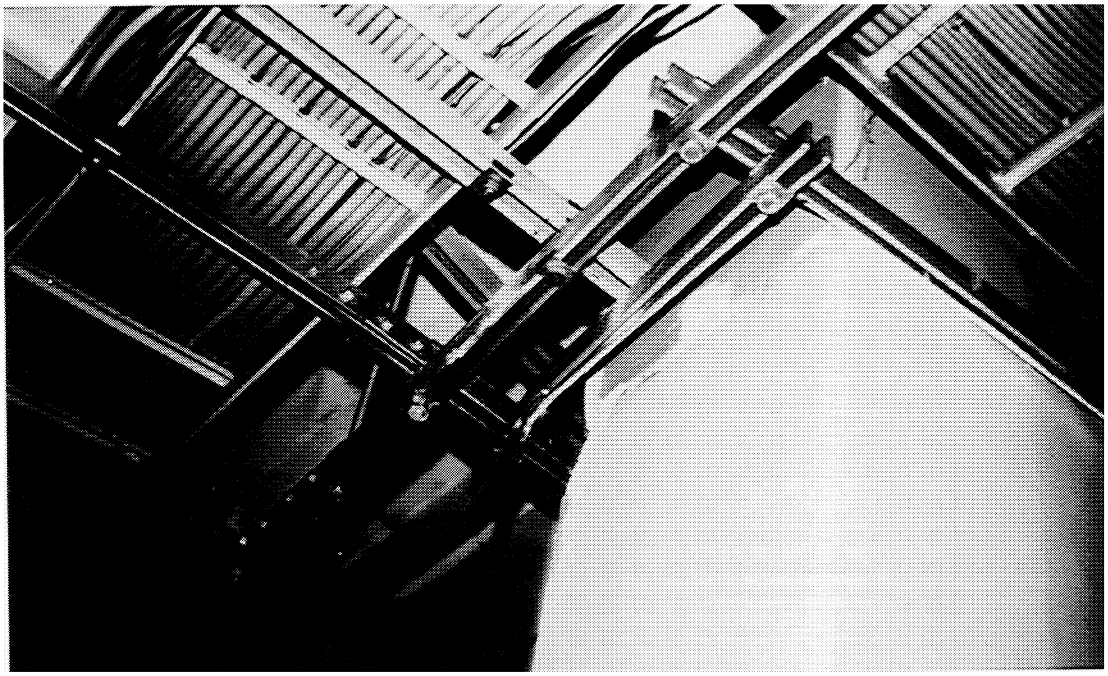

Figure 5 Movement of the framing system exceeded the clearance between the frame and the building structural column, causing damage to the framing system.

There have been many cases where the strength of the auxiliary framing members was inadequate and the members buckled, Figure 6. In most cases the framing members buckled as a unit; however there are cases were the channels that made up the member separated because they were not adequately tied to each other.

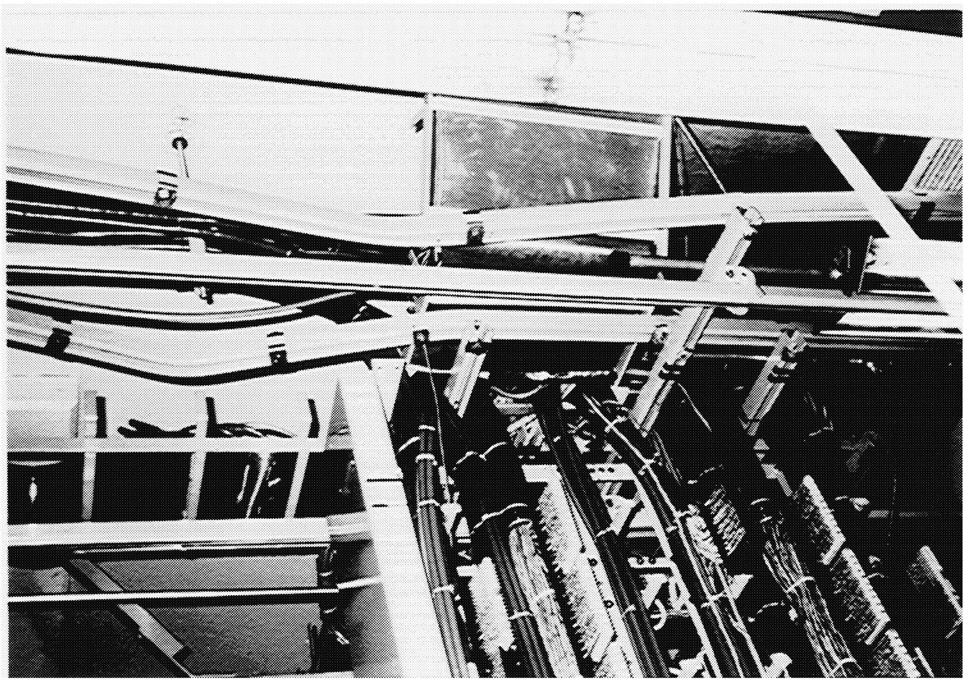

Figure 6 Lateral loads exceeded the capacity of the framing member causing it to buckle. This allows large relative motions of the framing system that can cause impacting of the frame with building columns or exceed the slack provided to conductors.

Another common failure mode is the failure of the framing system supports. The most common problem is the failure of cast iron cast-in-place inserts that attach the top of the support rod to the ceiling. There have been a few cases where expansion anchors have pulled out a concrete cone, as shown in Figure 7. There have also been failures at rod couplings, that is, where rods are screwed into a threaded tube. These failures appear to be associated with quality control during installation, as one of the rods only engaged a few threads when it was inserted into the coupling. Again, it should be emphasized that a contributing factor to most of these support system failures is the overloading of the cable racks.

The failure of framing member splices, as was the case with cable racks, has been a problem. In the case of the framing system, the problem is more severe because this system serves as a structural support system. There have been cases where splices have separated. Also there is no continuity of moment capacity across the splice. If a framing system support fails, the increased moment on the frame has caused the frame to buckle at the splice, Figure 8.

The performance of cast iron, cast-in-place hanger rod anchors has been poor. The cast iron cracks and the hanger rod support is lost.

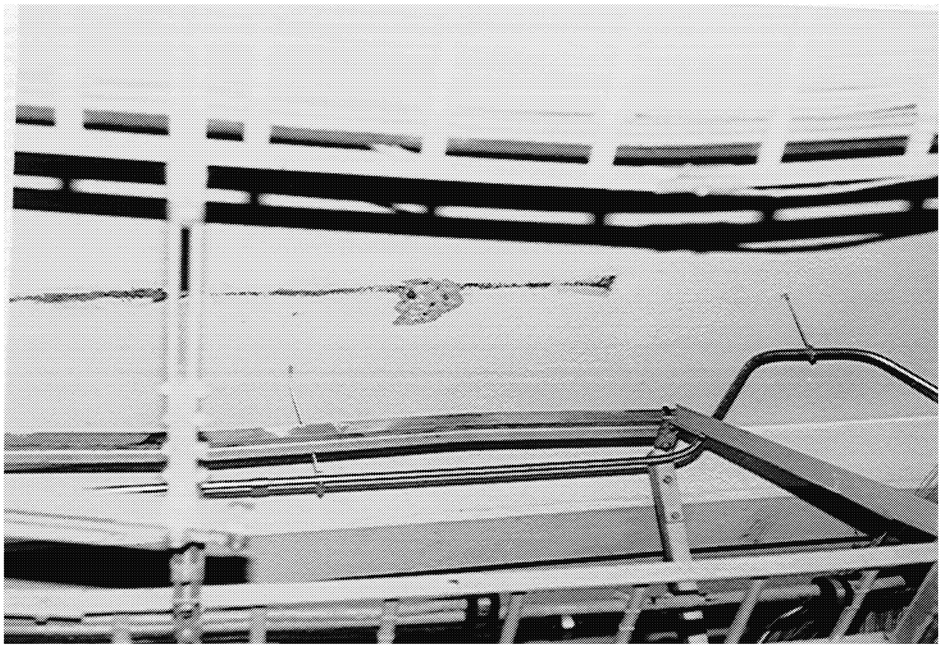

Fig. 7 The load on an expansion anchor caused a concrete cone to be pulled from the floor.

Figure 8 The buckling of the framing system at a splice demonstrated the lack of capacity of the friction clip splice.

Earthquake Performance of Switching Equipment

In North America, the only recorded catastrophic equipment failure occurred in the San Fernando Valley 1971 earthquake, Figure 3. Where NEBS standards have been used, the performance of this equipment in subsequent earthquakes has been good. Some early electronic equipment experienced disengagement of printed circuit boards because they had no positive restraint to prevent disengagement due to vibration. New equipment has incorporated positive latching to prevent card walkout, as required by the NEBS standard.

Conduit and light fixtures which span lineups have been damaged when the motion between adjacent lineups exceeded the slack provided or the strength of the light framing members used to tie the lineups together.

Disk drives have been damaged in earthquakes. Individual units are typically unanchored so that adjacent units may impact each other or adjacent structural members. The shock associated with the impact is probably the major contribution to damage to disk surfaces.

Collateral damage to equipment has been observed in many post earthquake investigations. In one incident, water leaked into the equipment when an overhead water pipe was broken. There are other cases where spares cabinets that are not anchored overturned in front of switching equipment. There has been damage to water tanks, water pipes on the roof, and water pipes within the building. Leaking water has made its way into equipment at PBX facilities.

While much of the electro-mechanical equipment in areas of high seismic awareness has been braced to strengthened framing systems, in other areas of the country this equipment is still vulnerable to San Fernando type catastrophic failures. The cost of retrofitting may be prohibitive when risks are considered for some regions, but when planning installation of new electronic equipment, the proximity of unstrengthened old equipment to the new equipment should be considered.

New equipment has other potential problems, but they have not been well documented. Logic circuit failures or processor failures caused by damaged connections or intermittent contacts can cause the whole system to malfunction. Also, flexible equipment racks can have large displacements that can damage the printed circuit boards or break the cable connections.

Earthquake Performance of Transmission Equipment

The performance of transmission equipment has been very good, except in the San Fernando earthquake, as described in the section on switching equipment.

While no modems are known to have been damaged in an earthquake, these units could slip from their support, since they are not secured, and could damage the ribbon cable that connects the modem to other equipment.

Microwave equipment has not been damaged, but methods for routing waveguides have been observed to be very vulnerable. Contributing to this vulnerability is the fact that microwave equipment is often located high in the structure so that it experiences amplified motions of the structure. Figure 9 shows a waveguide passing within 3/8" of a cable rack. The transmission rack is not anchored to the cable rack so that in an earthquake the relative motion could damage the waveguide hardware. In a PBX installation, the waveguide passes through a hole cut in the ceiling tile adjacent to a T-bar in a suspended ceiling. In an earthquake, the ceiling would likely swing and damage the waveguide hardware, Figure 10.

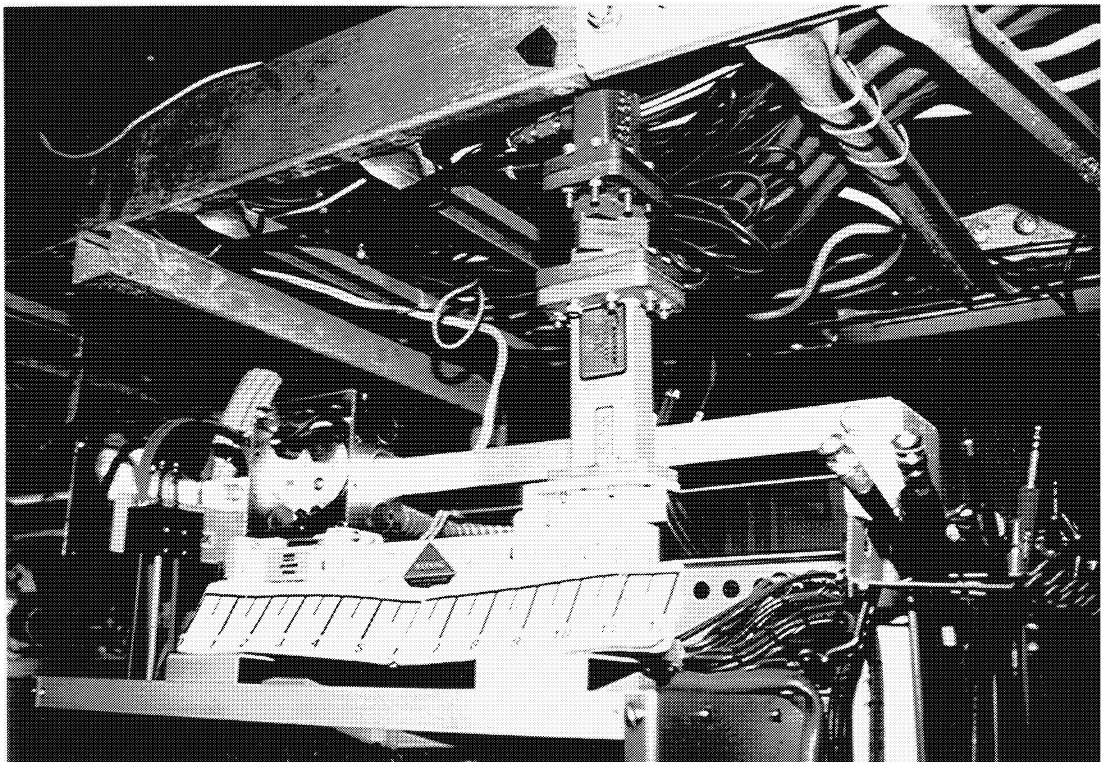

Figure 9 The connection between the waveguide and the output amplifier is secured with small screws that can only withstand very limited loads. There is very little clearance between the waveguide and cable tray.

Earthquake Performance of Control Rooms

The most common problem with control rooms is damage associated with ceilings. This occurs even with stringent building codes used in California. Ceiling panels around the periphery of the room and adjacent to columns frequently fall. When these panels are constructed from light-weight materials, the falling of the panels is more of an inconvenience than a hazard; however, some ceilings use more substantial metal or composite panels that could cause injuries if they strike personnel. Light fixtures have frequently fallen from their T-bar supports, but are restrained if provided with separate ceiling supports. There have been cases where the entire ceiling has fallen. In regions with less stringent building codes extensive damage can be expected.

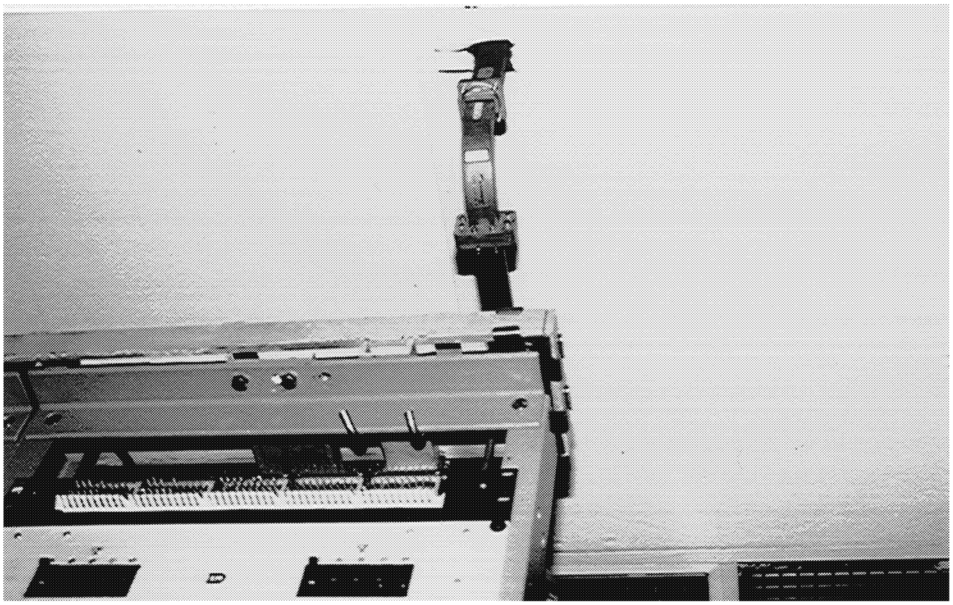

Figure 10 A waveguide passes though a suspended ceiling; it is vulnerable to loads imposed on it when the ceiling swings in an earthquake.

Control consoles have moved and pinched cables entering the console through the floor, although their functionality was not impaired. Video displays have fallen to the floor and been damaged.

Earthquake Performance of Control Rooms

The most common problem has been with equipment moving or tipping that is not anchored. Equipment slides and strikes adjacent equipment, walls or building columns. Equipment casters or leveling supports fall into holes cut in the floor for cable entry, and tip over. Floor panels pop up. In systems that do not have stringers connecting to pedestals, there have been partial collapses of the raised floor system.

There have been water leaks and water has collected below the raised floor and cable connections have gotten wet and have been damaged.

In a Japanese computer facility using similar installation practices, computer tape decks fell over, Figure 11.

Earthquake Performance of Electric Power Systems

Commercial electric power interruption has occurred in most damaging earthquakes, so that the UPS systems in the COs were called upon. When commercial power is disrupted, engine-generators are required to start, even though batteries could maintain the system for several hours. The performance of the batteries has generally been good. However, engine-generators have frequently had problems.

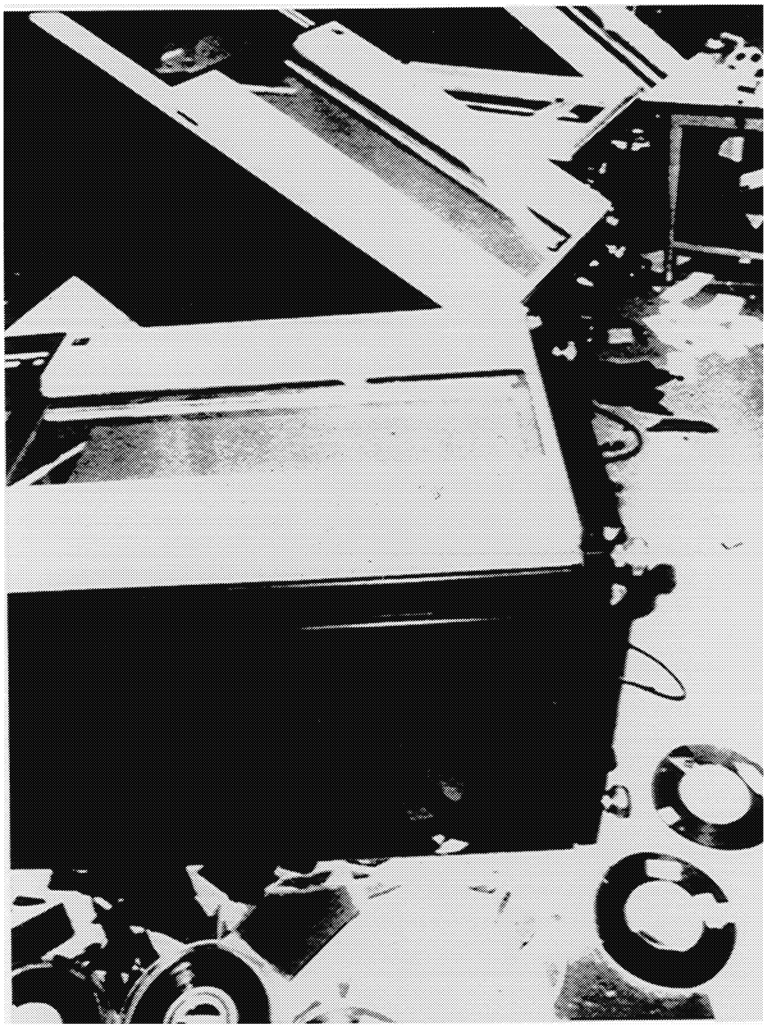

Figure 11 Signal and power cables restrained lateral movement at the base of the computer tape drive. Lacking restraints at the top and vertical restraint at the base, the tape drive fell over.

In the early seventies batteries were often not restrained to their racks, Figure 12, so that cells would fall to the ground and be damaged. When cell restraints were added to the racks, the racks often could not resist the earthquake induced loads and the rack anchorage would fail or racks would buckle, Figure 13. In some cases the battery racks were braced at the top to the framing system. It appears that the battery rack may have been stiffer than the framing system so that the battery rack would attempt to restrain the framing system. There were also cases where end cell restraints on the racks were lacking, side restraints had large gaps between the restraint and the cells, and there were gaps between cells so that impacts would crack battery cases creating acid spills and loss of voltage. A series of standard battery racks evolved through several design changes. Many of these racks are still in service but their performance has been mixed. Some versions of these racks were fabricated from light-gauge sheet metal or lacked adequate stiffening gussets and buckled in earthquakes, Figure 14.

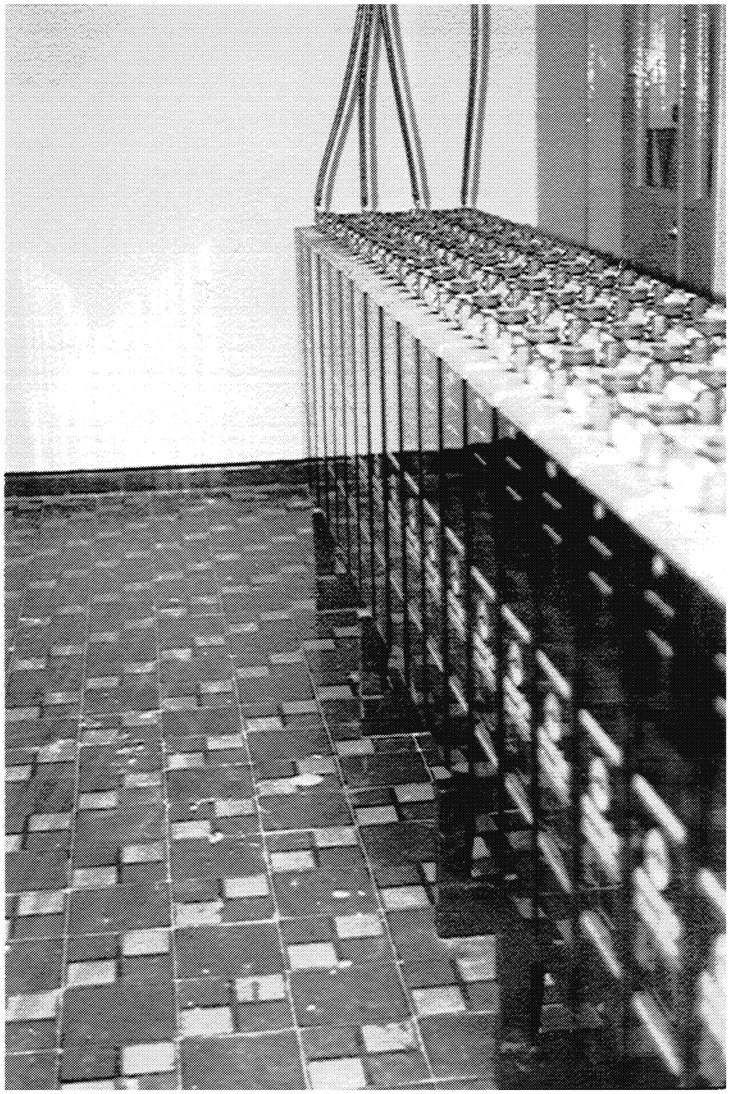

Figure 12 A battery rack without cell restraints. In an earthquake the cells may fall from the rack, and their cases crack. The operation of the UPS is thereby disrupted.

Emergency generators have experienced a number of problems. Batteries used to start the generators were unrestrained and would be damaged so that they were unavailable to start the engines. The engine generators would shift when their vibration isolation systems, which were often constructed with cast iron components, failed. Several engines have overheated because the load demand, over time, had increased above the design capacity of the generator. Fuel, oil, water or electrical lines have broken. Unanchored day tanks have slid or tipped over. Cooling system lines have been damaged and the loss of municipal water has disrupted the supply of make up water. Sometimes engine-generators would stop or fail to start and personnel would not be aware that the system was running on the battery plant until a low voltage alarm would sound.

DC bus or distribution lines have been distorted or damaged, causing short circuits that have disrupted the entire DC supply. Vibration has loosened cable connections to batteries.

Figure 13 One of the standard battery racks failed because it was fabricated from thin sheet metal and had inadequate gussets.

Earthquake Performance of Buildings

There are two known cases of telephone equipment building collapse; they are the long distance office in Mexico City and the CO in Armenia. In the Mexico city case only the top two floors collapsed. However, the long distance telephone equipment was on the top floor, as shown in Figure 14. The CO in Leninakan, Armenia, collapsed and was gutted by fire. In North America, there have been reported cases of structure damage, infill wall cracks, concrete spalling, and the failure of structural shear walls; however, no collapse has been reported.

Earthquake Performance of HVAC Facilities

The earthquake performance of HVAC systems has been mixed and is a major concern. Due to structural amplification of the CO building, the seismic environment on the CO roof is the most severe. Piping has been torn from its supports, Figure 15; heat exchangers, which are often mounted on vibration isolation systems, have fallen from their supports and tipped over. Cooling towers have been damaged due, in part, to corrosion and poor maintenance of components, and piping has been damaged due to the relative motion of support structures. Figure 16 shows a flexible coupling that was damaged due to the relative movement of a pipe anchored to the roof of the penthouse and the chiller that was

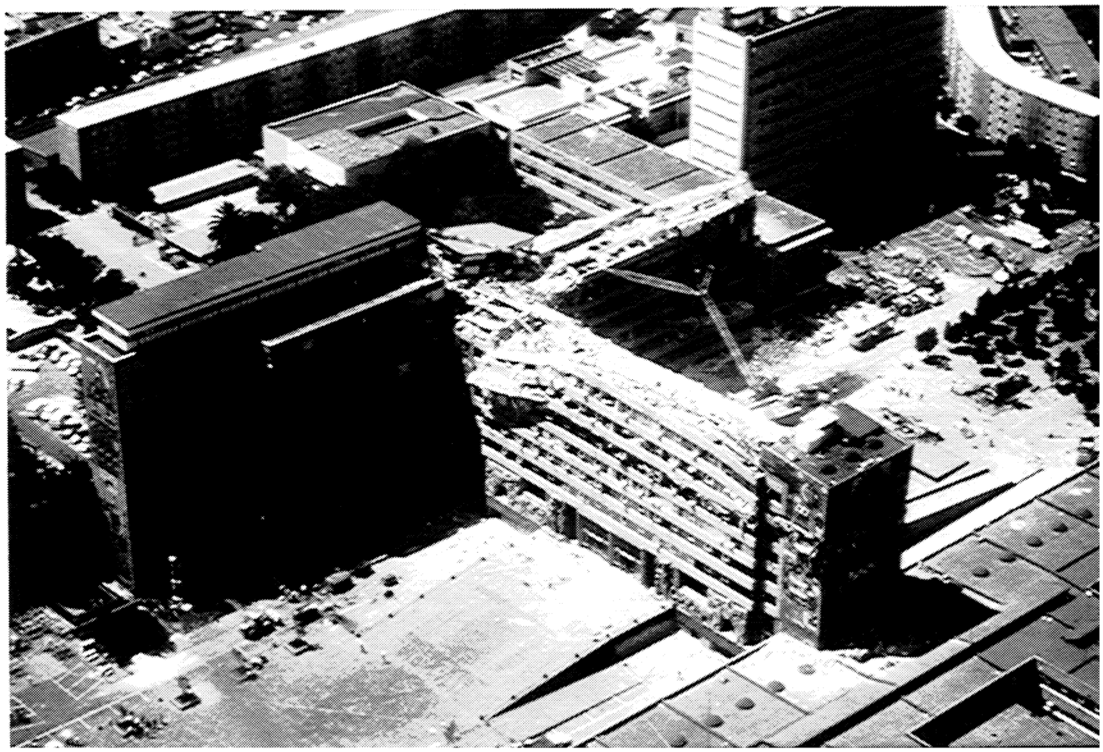

Figure 14 Collapse of top floors of CO in Mexico City disrupted all international calls to and from Mexico.

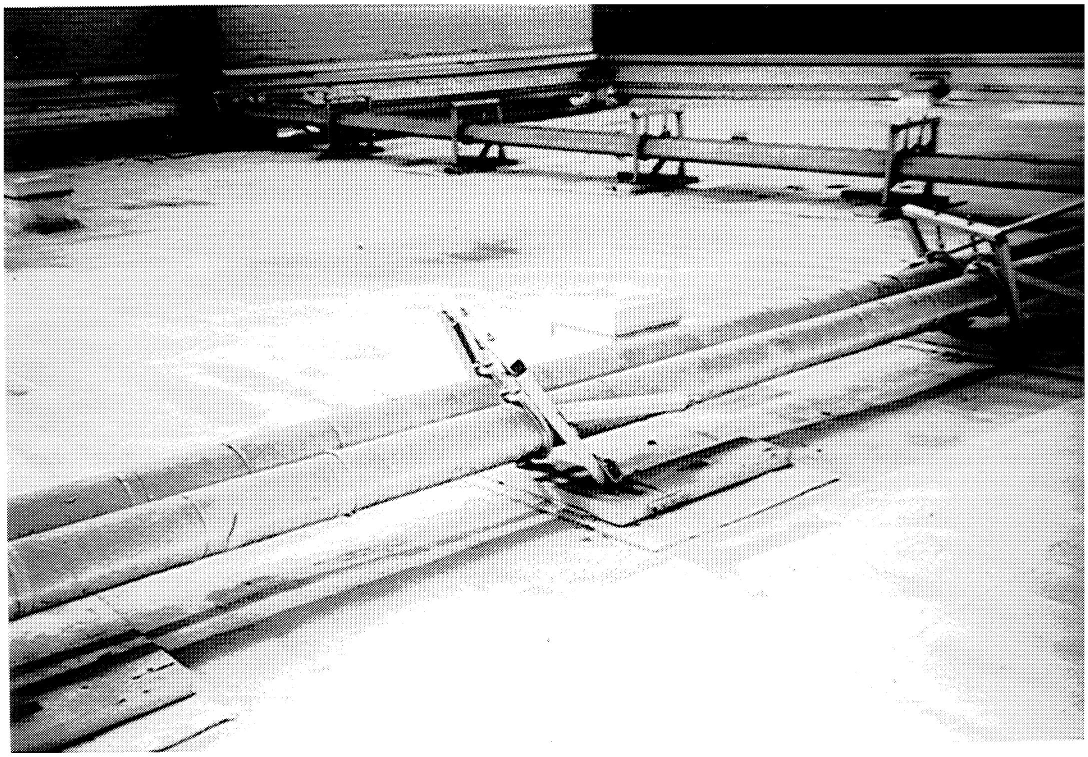

Figure 15 Amplified motion on the roof of a CO has caused the failure of HVAC piping supports.

Figure 16 A flexible coupling could not accommodate the relative motion between the roof of the penthouse, which supported the pipe, and the floor, which anchored the chiller.

anchored to the floor of the penthouse. Heat exchangers in computer rooms, similar to those found in COs, were poorly anchored, moved, and damaged piping connections. A common detail is to connect the upper part of the heat exchanger to the lower part with sheetmetal screws, as shown in Figure 17. Air diffusers on ducts have fallen. Damage to some penthouses has been so severe that access for repair of equipment could not be gained until the penthouse was shored up.

Earthquake Performance of Spare and Back-up Supply Storage

Spare parts are often damaged and the inventory is disordered because the parts are not properly stored.

Other Building Systems

Water and Fire Suppression Systems

Some multi-story CO buildings have office and equipment areas. Office areas may have water sprinkler system for fire suppression, while equipment areas will usually have fire extinguishers or Halon systems that are compatible with electrical equipment. If sprinkler systems in office areas are activated or if water pipes break or leak, water may find its way to equipment areas on lower floors. It is recommended that plastic sheeting be kept available so that it can be placed over equipment to shield it from water leaking through the ceiling.

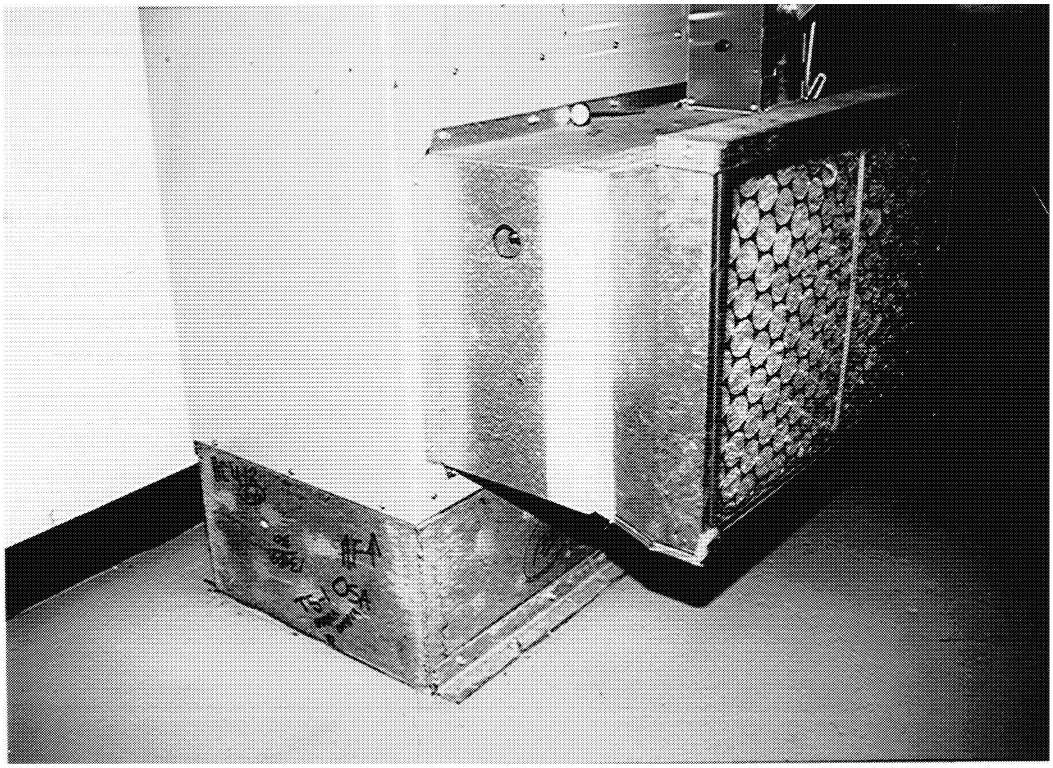

Figure 17 The upper part of this heat exchanger, which holds the piping, is only secured by sheet metal screws. If these fail, the pipes provide the only restraint.

Some PBX owners use a dry sprinkler system over the MDF and in areas with a large volume of cables.

Water supply failure can affect the cooling system which in turn can affect the electronic and digital equipment performance. Broken pipes or damaged sprinkler heads can cause water damage to electrical equipment. Most HVAC equipment do not have any seismic protection inasmuch as they are not considered critical equipment. These systems usually have water lines connected to them, so that pipes can break or leak and cause flooding in critical areas.

Electric Power Distribution

Central office lighting, test equipment and printers require commercial AC power. Power distribution panels are located on each floor and outlets are distributed throughout the floor. Conduits are sometimes used to route cables, but armored cables are also used. The distribution panels are normally anchored to the wall and conduits or armored cables are anchored to the walls with clamps. A wide range of anchor types is used in the power distribution system. Normally, little consideration is given to seismic protection for the power distribution system, however, its performance has been good.

Utility owned distribution transformers are usually located near the CO. This units are typically unanchored, even in California. These units have shifted in earthquakes and can cause a local power failure. It is recommended that the utility be requested to anchor the distribution transformer that provides power to the CO.

Elevators

For multi-story buildings, service elevators are necessary for moving heavy equipment between floors. The seismic performance of elevators in California has been mixed. The revised elevator code in California, implemented after the San Fernando earthquake, required some retrofits. The national elevator code that was modified for improved earthquake performance a few years later did not require any retrofits. If elevators may be needed after an earthquake, the anchorage of elevator equipment should be verified. Older central offices may have been provided with an external hoisting system so that heavy or large equipment could be brought into the building through windows.

Outside Plant

The outside plant can be divided into transmission media and components, as indicated in Table 2.

Table 2 Outside plant transmission media and components.

Transmission Media	Components
Outside Plant Cables and their Supports	Repeaters
Radio (Micro) Waves	Towers
	Manholes and Handholes
	Cross Connects and Protectors
	Special Conveyance
	Subscriber Equipment

Earthquake Performance of Outside Plant Cables and their Supports

Cables and Support Hardware

The earthquake performance of outside plant cables has been very good. There have been several earthquakes in the US in which large ground deformations have occurred due to liquefaction and lateral spreading and cables have not been damaged, although the conduit has been damaged. In the 1995 Kobe, Japan, earthquake there were extensive areas that experienced large ground deformations and conduits were damaged. This type of conduit damage has the potential for damaging cables, but reports on cable damage were inconclusive.

In the US there have been several incidents where post-earthquake structural fires have damaged nearby aerial cables, Figure 18. In the Kobe earthquake large areas were destroyed by fire, Figure 19, that destroyed most structures and the communication system. In the 1994 Northridge, California, earthquake a gas main in the street broke, caught fire and destroyed two 24-fiber optical fiber cables. In the Landers, California, earthquake two buried cables failed at a fault crossing, Figure 20. The fault offset at the cable failure locations is not known, but the maximum offset in this earthquake was about 25 feet.

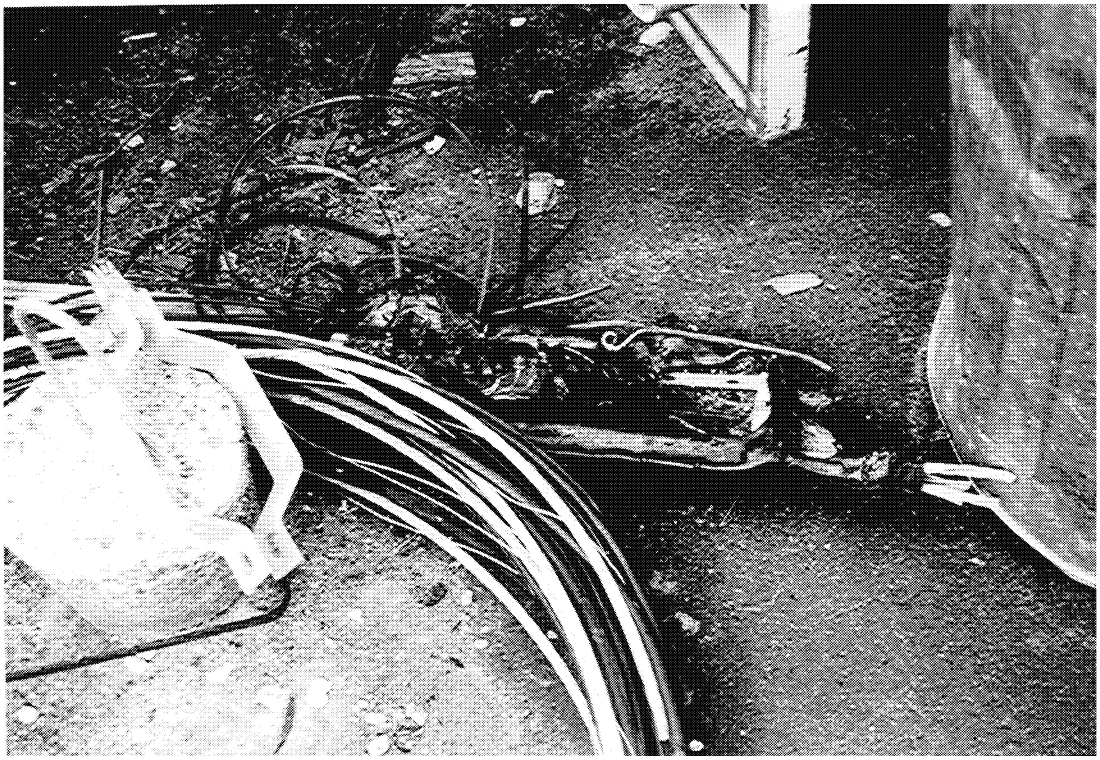

Figure 18 A splice enclosure was destroyed by a nearby structural fire caused by an earthquake.

Support Structures

There are many cases of earthquake damaged poles; however, when considering to the large number of poles that have been exposed to earthquakes and the wide distribution of poles, the relative performance is good. Four failure modes have been observed. Figure 21 illustrates the four failure modes. In liquefied soils, poles have tipped over or have sunk into the soil, Figure 22. Poles have failed at or just below ground level due to severe dry-rot. Poles have also failed near the top, typically at a cross arm. The failure of the body of the pole has been attributed to the loads induced by the ground motions or to being pulled over when an adjacent pole failed. In Kobe, Japan, many poles were damaged when houses collapsed and fell against the pole. Earthquake induced landslides have also damaged poles. Based on the experience in Kobe and the US, wooden poles have performed better than concrete poles. While the power circuits are primarily affected by failure near the cross arm, the telephone company may have to reinstall their lines

Figure 19 Large areas were destroyed by fire after the Kobe, Japan earthquake. Aerial cables and their wood support poles are vulnerable to fire.

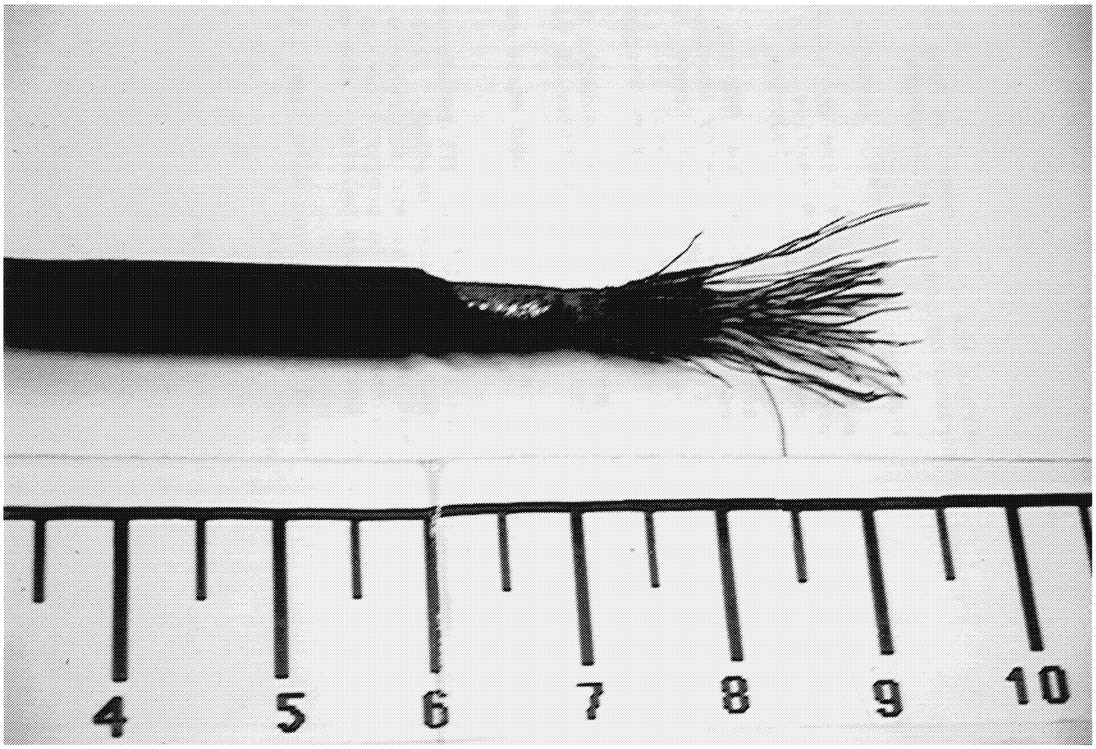

Figure 20 A 25-pair copper cable was broken where it crossed a fault.

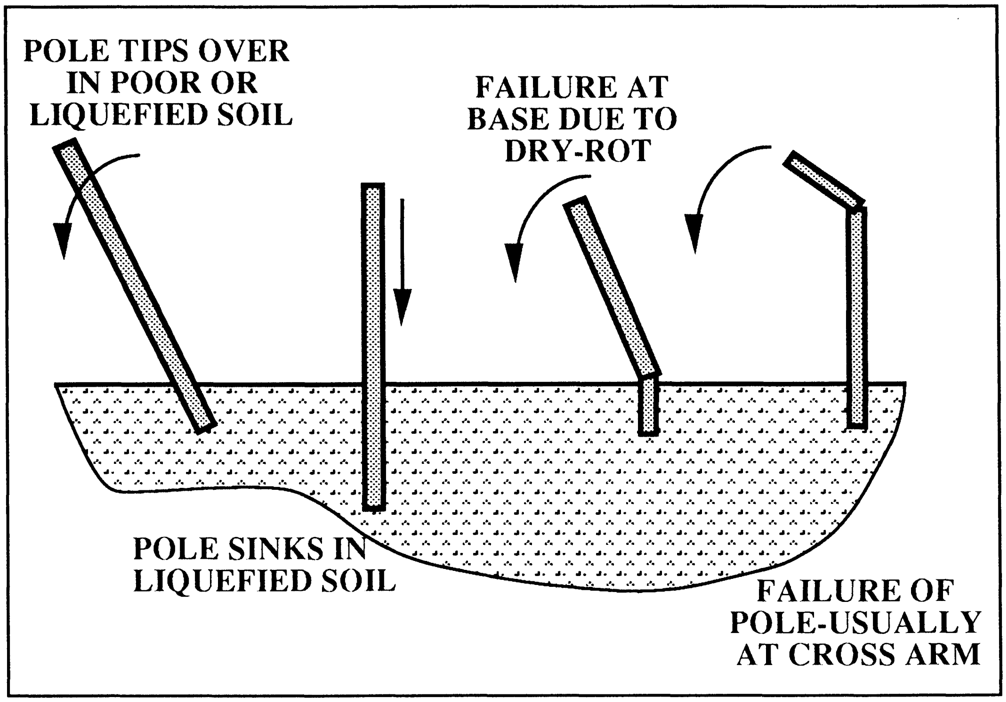

Figure 21 Four types of utility pole failures have been observed.

when the pole is replaced. Poles typically carry distribution lines that serve a limited area, so that distribution line disruption due to pole damage tends to be local. Most of the time, it is the drop wire from a pole to a subscriber that is damaged. Fires, after an earthquake, can destroy the entire distribution system over a large area as occurred in Kobe, Japan. Even in areas that were not totally destroyed by fire, outside plant was severely impacted, Figure 23. Trunk lines are occasionally carried on poles. Significant damage was inflicted on the communication system even when the area did not burn. In the Northridge earthquake, Figure 24. Two optical fiber cables were destroyed in the Northridge earthquake when a nearby gas main failed and caught fire.

Earthquake Performance of Repeaters

The earthquake performance of repeaters has been good, however, when commercial power is lost, battery back-up will run down after several hours. While portable generators can be provided to these sites, in a major earthquake the number of sites needing portable generators may overwhelm service crews dealing with other problems. As noted above, microwave repeaters are typically located on ridges and mountain tops. Ground motions tend to be more severe at these locations and access to make repairs may be difficult because of damage to roads and landslides. Severe ground motion on ridges has damaged microwave towers.

Figure 22 This pole sank about five feet when the soil supporting it liquefied.

Earthquake Performance of Towers

In the US there is almost no record of significant damage or failure of microwave tower structures. Minor buckling has been observed on towers. There have been cases where the dishes have become mis-aligned; this has generally been attributed to slipping or distortion of the hardware used to attach the dish to the tower. There have been cases of collapse of tall, guided radio towers.

The most significant earthquake damage was to a large microwave tower in Kobe, Japan. One of the legs buckled, which caused the entire tower to lean. The tower was removed. It should be noted that because of the high risk from strong typhoons, large wind loads are used in tower design in Japan. The poor soil conditions in Kobe may have contributed to the failure.

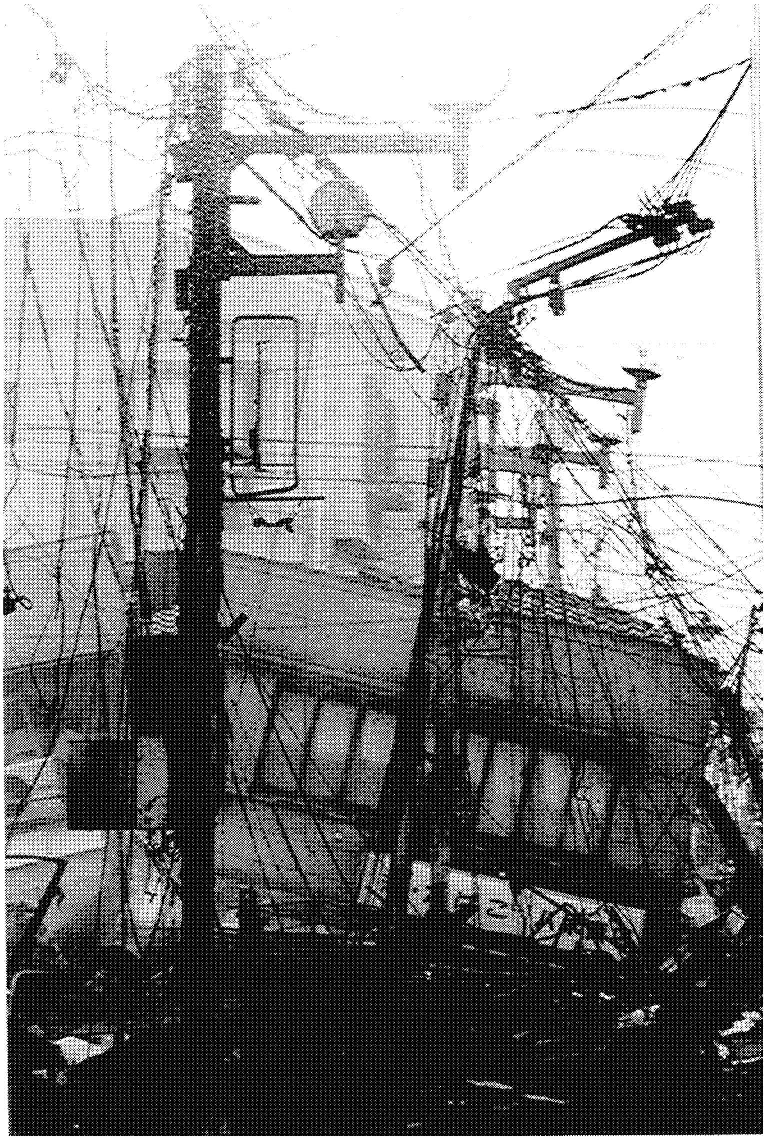

Figure 23 Even where fire did not destroy the area, communication systems were severely impacted.

Earthquake Performance of Manholes, Handholes and Conduit

There have been numerous failures of manholes, handholes and conduit, but, as noted in the section on cables, the cables within these systems typically were undamaged although there have been cases where cables have been damaged when a conduit fails. When conduit is damaged, water can invade the enclosure and small flaws in cables will eventually allow water the enter and degrade cable performance. The failure of these facilities is usually associated with soil liquefaction or the subsidence of poorly consolidated soils. In the US, there is no record of communication manholes failure, but failure of manholes used by sewer systems are not uncommon. In the mid-west, where more soil liquefaction is anticipated, more manhole and conduit damage can be expected.

Figure 24 This concrete power pole failed due to induced vibrations in Kobe, Japan earthquake.

As noted above, manhole failure is usually associated with soil liquefaction and two types of failure can occur. The soil around the manhole liquefies, that is, it loses its shear strength, and the manhole can sink or float, breaking conduits connected to the manhole. This is illustrated in Figure 25. Liquefaction effects can cause movements of over a foot, Figure 26. The second type of failure is associated with lateral spreading, in which the soil liquefies and its lateral movement can damage conduits and manholes.

Earthquake Performance of Cross Connects and Protectors

The earthquake performance of Cross Connects and Protectors has been very good, except that they have been damaged by fire after earthquakes.

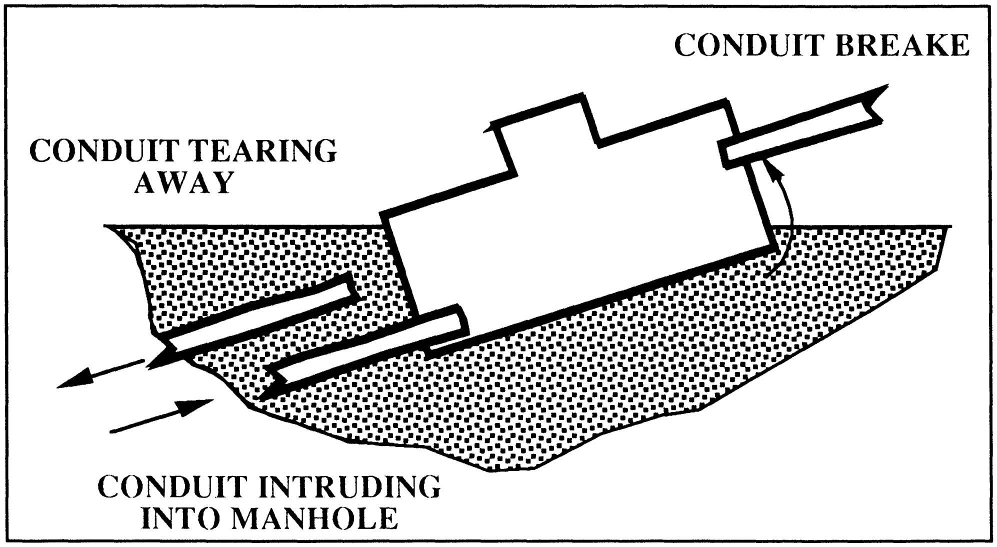

Figure 25 Damage to conduit when a manhole floats to the surface when surrounding soil liquefies.

Figure 26 There was relative motion between this manhole and the surrounding soil. The relative motion could have been due to floating of the manhole or subsidence of the soil. Conduits connected to the manhole were damaged. (Kobe, Japan)

Earthquake Performance of Special Conveyances

In general, the performance of special conveyances has been very good; the cables associated with them have also performed well. During the 1989 Loma Prieta earthquake, an optical fiber cable routed along the Bay Bridge came down with the deck section that failed, Figure 27. Amazingly, the cable survived. Although, three out of more than 90 fibers were damaged, the robustness of the cable was demonstrated, as was the importance of slack when running cables. This provided a good example of a lifelines collocation problem, which are commonly associated with special conveyances.

Figure 27 A section of the upper deck of the Bay Bridge between Oakland and San Francisco failed. A conduit that carried about 90 optical fibers was connected to the upper deck. The conduit broke away from the upper deck when it fell, and experienced significant deformation. Most of the optical fibers within the conduit were undamaged.

Earthquake Performance of Subscriber Equipment

Most subscriber owned equipment performs well in earthquakes, except that hand sets may come off hook or the entire set may fall to the ground. Hand sets knocked off hook are very common in earthquakes. In one area in Northridge, about the 10% of the line failure alarms were due to off hooks. Modern digital switching equipment is capable of differentiating between a line failure due to off hook or a severed line. Therefore, CO records can provide a quick reports of the performance status of the network served by the CO. Lines can be released through manual intervention. Although this will require a few minutes, it is critical in terms of emergency response.

Wireless Network

The wireless network can be divided into the components listed in Table 3.

Earthquake Performance of the Wireless Network

The earthquake performance of the wireless system has been mixed. While these systems have experienced little earthquake damage, there have been congestion problems. The system is rapidly evolving and in some earthquake locations, there is excess installed capacity, so that additional phones could be added to the system without significantly degrading local access to the system. In other areas, the influx of phones from outside the area and the distribution of additional phones has caused local congestion problems. Even if the wireless system remains congestion free, there will still be problems of accessing the PSN. Some wireless companies have mobile cell sites that can be deployed so that capacity can be expanded, but there is a limited number of these facilities.

Table 3 Wireless network elements

Network Elements
Technical Description of Network
Subscriber Equipment
Cell Sites
Transmission Towers and Antenna
Mobile Telephone Exchange

As noted above, equipment performance has been good, partly because these are new installations and conform to current seismic practices. The structures that house them are typically engineered, prefabricated box like structures that are similar to a small trailer truck body with a floor area of about 10 feet by 15 feet. There have been problems with limited battery life at sites that do not allow engine-generators. While a few local outages can be addressed with newly charged cells, in an area-wide blackout cells have been lost after a few hours. Because service areas covered by cells overlap, the loss of isolated cells may not cause a total loss of service, although the congestion problem will be aggravated.

The wireless system has become an important communication means during and after earthquakes, in part because it allows the user the flexibility to move over a broad area. In addition to emergency response teams, individuals whose desktop phones are rendered useless due to building damage or local disruptions to the PSN can use cellular phones to communicate. In some cases the use of cellular phones can work around the congestion of the PSN. However, these systems are also subject to saturation problems. Many organizations have incorporated cellular phones in their emergency response plans with the view that they will provide a reliable means of communication, which has not always been the situation after earthquakes, although this system has usually played a major role in post earthquake emergency response and recovery activities.

Issues Related To Performance Criteria

by

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Abstract

The seismic performance practices used for communication equipment have provided equipment with excellent earthquake performance. Prescriptive building codes are designed to prevent structural collapse, rather than post-earthquake functionality, which is required for many communications facilities. The upgrading of communication equipment in a central office does not require that the structure be brought up to current seismic codes. Thus, central offices that predate modern building codes are vulnerable to severe earthquake damage. The ability to develop standards and codes that can be used to assure that complex systems, such as communication networks, will perform as prescribed is not assured at this time.

Equipment, Building, and Communication Performance Criteria

Current criteria use both performance criteria, such as testing of communication equipment to a specific test response spectrum, and prescriptive codes, such as are found in building codes.

The validity of performance criteria for communication equipment and its application to equipment has been demonstrated by the lack of damage to equipment in several earthquakes. The exception being when manufacturers' recommendations for anchoring equipment are not followed by installation contractors. The criteria for communication equipment are relatively simple and shake table testing and actual earthquake excitations provide a simple test of the validity of the criteria and their application. Performance criteria for more complex systems are discussed below.

Building codes are more problematic. Building codes are designed to prevent structural collapse. But facilities, such as central offices must continue to function after the most severe earthquake. While codes do elevate design levels for critical facilities, there is little technical foundation relating improved functionality to increases design coefficients. Many of the failures that will disrupt service are architectural features or building service systems that are not adjusted for critical facilities. While building codes evolve, usually getting more stringent as poor performance is discovered, central office building structures are seldom upgraded. In many parts of the country, central offices were constructed before modern building codes were in place. Traditionally, building codes do not require upgrading to current code unless significant renovation is performed. The upgrading of central office communication equipment does not trigger this mechanism for building upgrading.

For a complex system, such as a communications system, it may be possible to establish overall system performance criteria for service, and yet be unable to translate these into workable subsystem performance criteria, and installation, operating, and maintenance practices. Thus, performance measures such as the acceptable delay in dial tone and call volume are difficult to translate into acceptable concentration of trunks, central office size, or many other system features that affect system performance.

It is not clear how performance criteria can be verified for complex systems, such as the overall performance of a telecommunications system. The successful application of overall performance criteria to communications systems will probably require that the overall criteria be capable of being translated into more detailed and specific criteria to subsystems, which can be validated and verified.

System Performance Criteria for Telecommunication Networks

by

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Abstract

In recent years, there has been a shift in the definition of performance criteria for lifeline systems. Early definitions concentrated on the performance on critical and essential equipment, while later versions emphasized the system aspects of performance. This paper attempts to put into perspective the different ways of viewing system performance using earthquake as an example, and the various ways of measuring system performance. In order to define future research directions in this regard, several recommendations are provided which emphasize the importance of direct and indirect loss modeling.

Introduction

Central office buildings are generally simple structures that have been designed to house equipment not people. They are usually box-shaped in configuration and less than three stories. Because of security reasons, they are constructed with little or no window areas. Based on recent earthquake experience, these buildings have been fairly earthquake resilient.

In general, the problems that do occur in these facilities are related to inadequately anchored equipment or operational issues, such as customer overload during emergencies. Recent design standards or guidelines, however, have addressed even these problems.

An area that deserves further evaluation is the assessment of system earthquake performance measures or criteria for telecommunication systems. For example, have there been studies to assess the potential economic impact of earthquake-induced communication system failures on the banking industry? What would be the impact on simple business transactions such as payroll or payment of mortgages? In order to assess these impacts, methods or procedures for quantifying the effects of system disruption must be in place and the results shared with local businesses and government agencies. The purpose of this paper is to explore the feasibility of creating such methods and using the results to define acceptable system performance criteria for telecommunication networks.

Performance Measures

Performance measures for lifeline systems have been proposed in early papers and reports (Campbell et al, 1979). In general, these measures involve the number of people or customers without service, the expected outage times and the time required for full restoration of customer services. Proposed criteria assign acceptable levels to each of these measures and generally acknowledge that higher levels of performance would be expected for lower magnitude events. What is not included in these assessments are the economic costs or losses that are associated with the disruption of service to critical businesses.

In order for system performance criteria to be adopted, it is critical that economic losses to impacted businesses be considered. Although most telecommunication companies are regulated either by state public utilities commissions or the Federal Communications Commission, the implementation of seismic design standards or guidelines has been largely self-imposed. To implement higher standards that would insure regional continuity of service, it would be necessary to demonstrate that certain business sectors will suffer unacceptably large losses if service were to be disrupted for an extended period of time. With more and more businesses now relying on the Internet as part of their operations, it becomes even more critical that the expected performance of telecommunication systems be quantified.

For purposes of discussion, the following additional measures are proposed:

1. Direct economic losses caused by a disruption of telecommunication services.
2. Indirect losses caused by the failure of businesses that are directly or indirectly impacted by telecommunication system failures and disruption.

Required Methodologies

In order to assess the impacts on businesses, new loss estimation methodologies are needed. These methodologies must allow for broad regional quantification of losses, that is, they must be scenario-based and include an inventory of major businesses or economic sectors. The output of these methodologies must also include an assessment of both direct and indirect economic losses. Direct losses will include all estimated repair costs, while indirect losses will include all business interruption losses caused by a disruption of telecommunication services. Indirect losses will be affected by which businesses have been directly damaged in the earthquake and the time of service disruption.

Indirect loss methodologies have been developed for assessing impacts from electric power, water and gas disruption (Chang et al, 1996). These methodologies are based on first assessing direct damage to critical facilities or transmission links, then determining which businesses or economic sectors depend on these services, and finally, determining business interruption costs or losses based on length of outage or service disruption. In general, these same methodologies should apply to the failure and disruption of telecommunication networks.

What would be required to implement these methodologies to telecommunication systems would be:

1. Fragility models for central offices
2. Detailed network models for local and long-distance systems
3. Inventory of local and regional businesses (economic models for various business sectors)
4. Restoration or outage models for telecommunication facilities
5. Business dependency models
6. Loss of business functions (business interruption models)
7. Methodology for performing direct and indirect loss calculations
8. Case studies or actual performance data

Future Research Directions

1. Perform loss estimation studies specifically examining the impacts associated with communication service disruption.
2. Examine performance data from both the 1994 Northridge and 1995 Kobe earthquakes.
3. Conduct a business survey to identify actual business dependencies on telecommunication services.
4. Translate the results of these studies into system performance criteria

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Factors Affecting Congestion (Change of Traffic Pattern) of Telecommunication Systems and Networks

by

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Abstract

This paper is intended as a starting point for discussions to address and identify performance issues related to congestion (meaning delayed dial tone and incomplete call attempt) on telecommunication systems and networks after a major earthquake in a populated area. The driving forces; technology, advanced services, market demand and competition, that are shaping the telecommunication systems and networks of the next century can be harnessed to serve post disaster needs. The time has come to develop performance criteria and policies in parallel with the growth and changes of the telecommunication systems and networks. The task ahead is huge and not easy; success will depend on collaboration of operators, vendors, providers of emergency services, policy makers, researchers and users.

The Wave of Changes

The Telecommunication Systems and Networks, consisting of physical elements called hardware and the soul called software, are becoming more complex due to four major factors; 1. technology advances, 2. integration of services[1], 3. market demand and 4. competition. These factors impact (positively or negatively) systems and networks congestion. Due to these four moving targets, the effort needed to establish earthquake performance criteria for telecommunication systems and networks is getting bigger and more difficult. The earthquake performance of the hardware (including lifeline interdependencies) of telecommunication systems and networks can be defined and guidelines can be developed. The elements, mainly software, created by integrating the physical components are yet to be understood and be analyzed such that issues to be addressed to establish system and networks performance criteria can be identified. The purpose here is to identify factors that effect congestion, there is no attempt to address congestion directly.

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[1] Services such as voice messaging, call forward, call waiting, inter-active functions, etc. integrate with voice service.

Technology, hardware and software, continues to create services and conveniences that are changing the way we live and do business. The growth rate of Web Sites is in thousands per month, compared with hundreds annually a couple of year ago; this is just one of the many ways we use the telecommunication systems and networks. Large Businesses are encouraging home base offices, or commonly known as telecommuting. Intelligent Networks (IN), a term used to describe a marriage between large scale computers and telecommunication systems, are the foundations of the fast growth of telecommunication systems and networks usage. For some businesses the special services offered by the operators and/or vendors provide them with the competitive edge. The traditional dial tone for voice services is now having a totally different meaning. It is being replaced by 'web-tone'; a service the new world will be built on. The telephone that we all know is slowly and definitely being replaced by computer with a telephone (voice) function.

It is not critical whether technology created demand or demand drove technology development. What is important is the fact that the system that we are all used to is changing and changing at a very fast pace. The action here is not to find ways to check the growth, the action is to manage and to utilize technology in terms of earthquake performance to protect users.

Competition, in terms of systems and networks providers (operators and vendors), is the driving force that created the networks (or systems). Operators and/or vendors consider the technology they deploy is the leading edge technology and will become the standard. That leads to compatibility issues and creates multiple networks. From business perspective, competition leads to cost/performance trade-off's in determining the systems and networks. The goal is to maximize the capacity[2] of the networks without additional physical components. Therefore, the reliability issues related to concentration and high capacity links have to be evaluated.

The Networks

Telecommunication networks provide any-to-any connectivity. Users expect seamless services while operators/vendors expect profitable services; hence the cost/performance trade-off's in establishing a networks.

A networks that connects all end users requires n(n-1)/2 links, where n is the number of users. It is impossible to provide this level of direct connectivity from coast to coast for all users. The cost is prohibitive. The solution is an 'optimal' networks with enough links to satisfy the (call) traffic pattern to meet the Grade of Service. In addition to this requirement, network survivability and congestion management have to be considered in network design. Network survivability is defined as the ability of the network to provide a minimum set of services in spite of failures, which may be caused by hardware, software or procedural error. While congestion management is handling of unexpected increase in demands to avoid system crash.

It is obvious that all systems and networks cannot handle the demand for service above the designed capacity. The demand for service right after an earthquake in a populated area has always

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[2] Capacity is defined as the number of circuits available in a given network. The unit of measure is either CCS or Erlang.

been higher than the networks capacity. This is the root cause of perceived networks (system) failure. Some data has been collected from Northridge and Kobe earthquake. The Northridge data is from one Central Office (CO) within the affected area, while the data from Kobe represents a summary of the incoming calls to the affected area. The data from the Northridge CO showed a 3-fold increase in call attempts in the first day after the earthquake (refer to Figure 1). During peak period, the call attempts was over 10 times normal number.

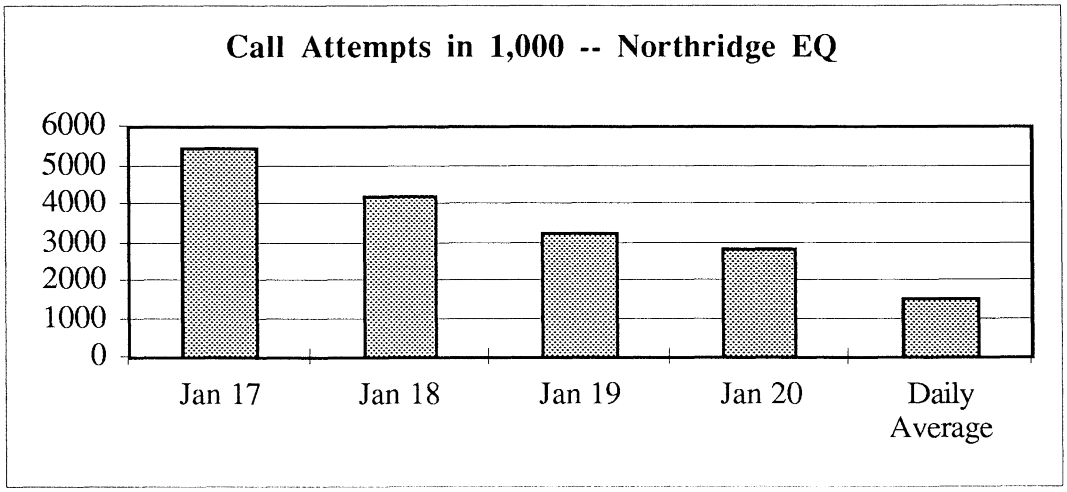

Figure 1 Increase in Demand after Northridge Earthquake (Data from one CO in Northridge)

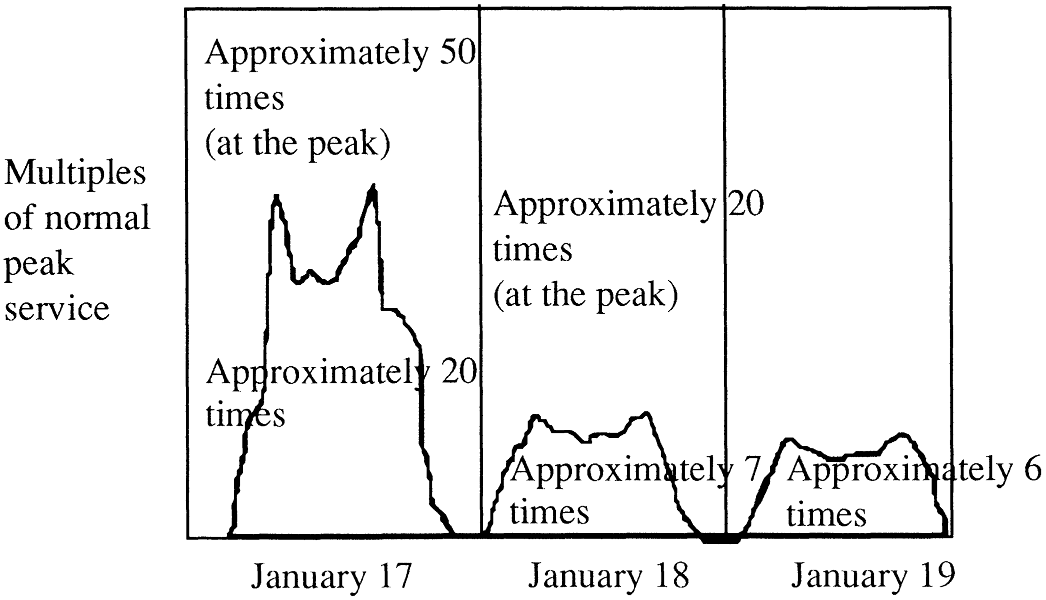

Figure 2 Incoming Calls from Around Japan to Kobe

In Kobe, a combination of outside plant damage and backup power failures, over 250,000 lines were out of service. Full restoration took 15 days (refer to Figure 3). The call volume at peak period in the first day after the earthquake was approximately 50 times normal (refer to Figure 2). Three days after the earthquake, the call volume was approximately 6 times normal.

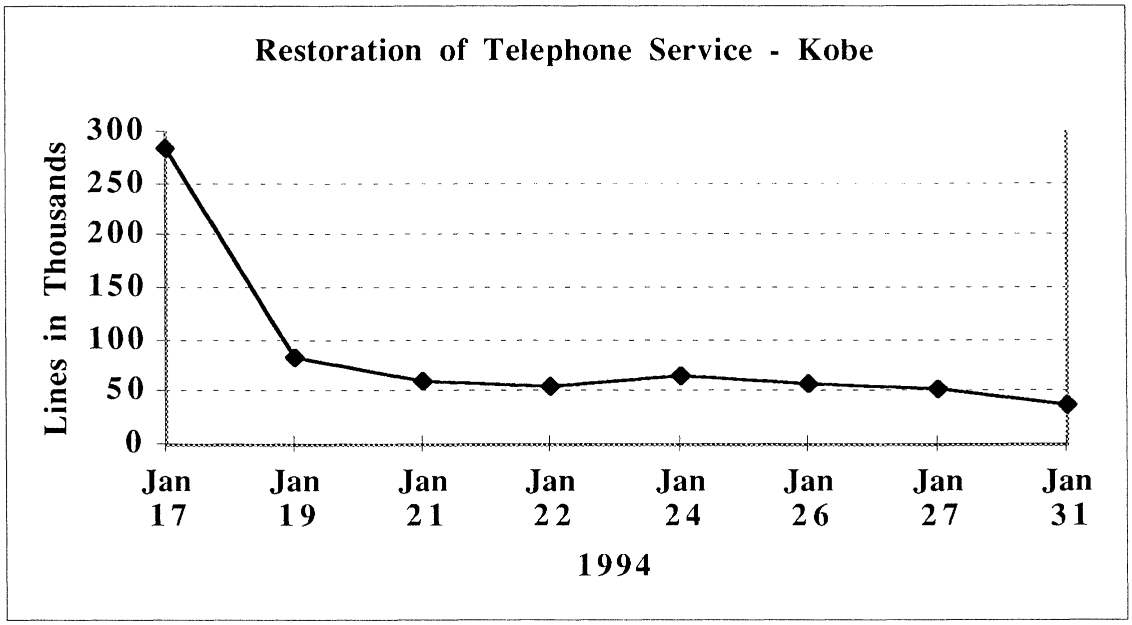

Figure 3. Data as of February 1st, 1995. About 40K lines were permanently out of service due to collapse houses.

The Impacts (Positive or Negative)

In late 1997, many operators and vendors of telecommunication systems and networks realized that the traffic pattern had changed. The traditional voice traffic pattern is overtaken by the internet users. The internet users, whether 'surfing' the web or emailing, dwell on the circuit longer; and much longer than expected. Applying longer dwell time (duration of call) on an existing networks means reducing the capacity of the networks. Therefore more capacity has to be provided to meet the need. This may be a good news to earthquake performance for voice users on condition that the internet users do not hog the system after an earthquake and there is no damage to the hardware.

Wireless networks (including Personal Communication System, PCS) is growing at a very fast pace. The main attraction of the wireless system is personal security. That is many subscribers do not use the mobile phone except for emergency. The Wireless networks is based on the same principal as the Wireline networks; there is a designed capacity. Any demand above the designed level will experience delay, in another word, congestion. The Wireless networks, in general, are not additional networks to the Wireline networks, due to inter-network traffic.

Most of the growth is not coordinated among the telecommunication system and networks operators and vendors. The ability of inter-system (networks) access makes it more difficult to determine the actual capacity.

Topics for Discussion

The data collected from Northridge and Kobe earthquakes reinforces the fact that increased demand for service will occur after an earthquake. That is congestion cannot be avoided. Therefore performance criteria discussion should be focused on how to manage the increase in demand within the networks capacity and how to utilize the technology to enhance performance.

One of the criteria in networks capacity design is dwell time of call; one of the controllable factors in the overall equation to calculate networks capacity. Reducing the dwell time will increase circuit availability, in another word increase the capacity of the networks.

As most calls in the aftermath of an earthquake are initiated outside the affected area, prompted by concern for the safety of disaster victims (i.e., more incoming calls than out-going calls), voice messaging technology can be used to direct these call away from the area to reduce the load on the local networks. Web sites can be set up outside of the earthquake effected area to allow access of information related to the disaster. These are some of the ways to reduce traffic on the immediate system and network.

The optical fiber cables connecting the systems and networks can handle a large number circuits. More users will be impacted by a severed link.

Other issues to be addressed are;

1. acceptable level of service reduction
2. acceptable interval/duration of service outage (in case of repairable damages)
3. acceptable level of capacity reduction (in case of permanent physical damages)
4. performance of regular services (voice)
5. performance of essential services, e.g. 911, emergency services
6. level of restriction in service
7. level of redundancy (to address outside plant concentration)
8. line load (traffic) control protocol
9. lifeline interdependency

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Emergency Power for Communication Systems

by

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Abstract

Recent California earthquakes have demonstrated that commercial power can be disrupted from moderate earthquakes. In central offices, battery plants and back-up engine-generators have failed for a variety of reasons to such a degree that one major telephone company has installed external power hook-up to facilitate the restoration of emergency power with mobile engine-generators. In cellular systems, may cell sites only have battery back-up power for a few hours. Consistent performance criteria should be established for all segments of the communication industry that include criteria that address the design, installation, operation, and maintenance practices as well as run times without fuel resupply.

Introduction

Recent Moderate and Strong United States earthquakes have demonstrated that the disruption of commercial power can be expected from future earthquakes. Disruptions have lasted from several hours to over twenty-four hours. There have been no Major or Great earthquakes centered in major metropolitan areas, and disruptions have occurred primarily in California, where earthquake construction and installation practices are generally better than in other parts of the country. The earthquake performance of emergency power at telephone central offices has been mixed. The causes of disruption of emergency power systems have been varied and some telephone companies have installed external power hookups so that mobile emergency power units can be quickly connected to provide power to central offices should existing systems fail. Many wireless system cell sites in urban areas are equipped with battery backup that can supply power for a few hours and do not have engine-generators to provide power for a lengthier disruption of commercial power. There is a need for overall performance criteria for emergency power systems that can be used to establish more detailed criteria that can assure acceptable performance of system components and system performance.

Seismic Reliability of Commercial Power

The USGS National Earthquake Information Center has established a scale for the size of earthquakes based on the Moment Magnitude, a measurement related to the energy released by the earthquake. Table 1 shows this scale and the number of earthquakes that have occurred throughout the world based on data gathered since 1900. An increase of one of the magnitude corresponds to an increase of over thirty fold increase in energy release. Thus, a Great earthquake will release about 1000 fold more in energy as compared to a Strong earthquake.

Table 1 Frequency of Occurrence of Earthquakes of Different Magnitudes*

Descriptor	Magnitude	Number/Year (average)
Great	8.0 and higher	1
Major	7.0 – 7.9	18
Strong	6.0 – 6.9	120
Moderate	5.0 – 5.9	800
Light	4.0 – 4.9	6,200 (estimate)
Minor	3.0 – 3.9	49,000 (estimate)

* USGS National Earthquake Information Center web site, Geologic Hazards, URLhttp://wwwneic.cr.usgs.gov/neis/eqlists.html/

Excluding the 1906 San Francisco earthquake, which occurred prior to the existence of modern communications systems, there has been no Major or Great earthquake centered in a metropolitan area. Starting with the 1971 San Fernando earthquake, there have been ten California earthquakes that have caused significant damage to power facilities. Of these, several have caused power disruption, and two that have caused wide-spread power disruptions that have lasted over twenty -four hours in parts of the service area. Because of the relatively high occurrence rate of damaging earthquakes in California, California utilities have improved seismic design and installation practices relative to other parts of the country. The earthquakes have also damaged some types of vulnerable power equipment that has typically been replaced with more seismically rugged equipment.

Given this history of damage and disruption from Moderate and Strong earthquakes in California, more extensive and lengthy power disruptions can be expected from Strong and Great earthquakes in California and from smaller events in other parts of the country.

Emergency Power in Central Offices

Central offices have traditionally operated switches and communication equipment from uninterruptable power supplies (UPS). These supplies can maintain service for three to eight hours after commercial power is lost. To continue operations for a longer duration, engine-generators provide back-up power. Figure 1 shows a block diagram of a large engine-generator system. All systems may not contain every component. Smaller systems may have an engine-supported radiator, lack oil coolers, and use bottled gas rather than diesel fuel. System components use mature technologies, although changes in regulations and technical developments stimulate some changes. For example, the Environmental Protection Agency now requires that the main fuel tank and the day tank be double-walled.

The performance of emergency power systems in central offices has been mixed. There have been failures to UPS systems due to the failure of battery racks and the shorting of DC bus supported by the racks. Failures of engine-generator systems have been more common and can be attributed to a variety of problems, some associated with installation, maintenance, and operating practices. The failure of the engine-generator system has been attributed to dead batteries used to start the engine; improper closing of cooling water lines or air dampers; degradation of fuel oil causing filters or injectors to become clogged; failure of engine vibration-isolation system that caused the failure of one or more utility lines; failure of the day tank support; overloading of the engine; failure of external cooling system components; failure to provide the fuel pump with emergency power; lack of makeup water for an evaporative cooling tower; failure of the municipal water support to provide cooling water; inability to resupply the main fuel tank, failure of a transfer switch due to poor maintenance; and failure of the fuel line from a propane tank when the unanchored tanked moved.

Many of these failures occurred at telephone companies that have very strong earthquake preparedness and mitigation programs and highly trained specialists who routinely maintain emergency power systems.

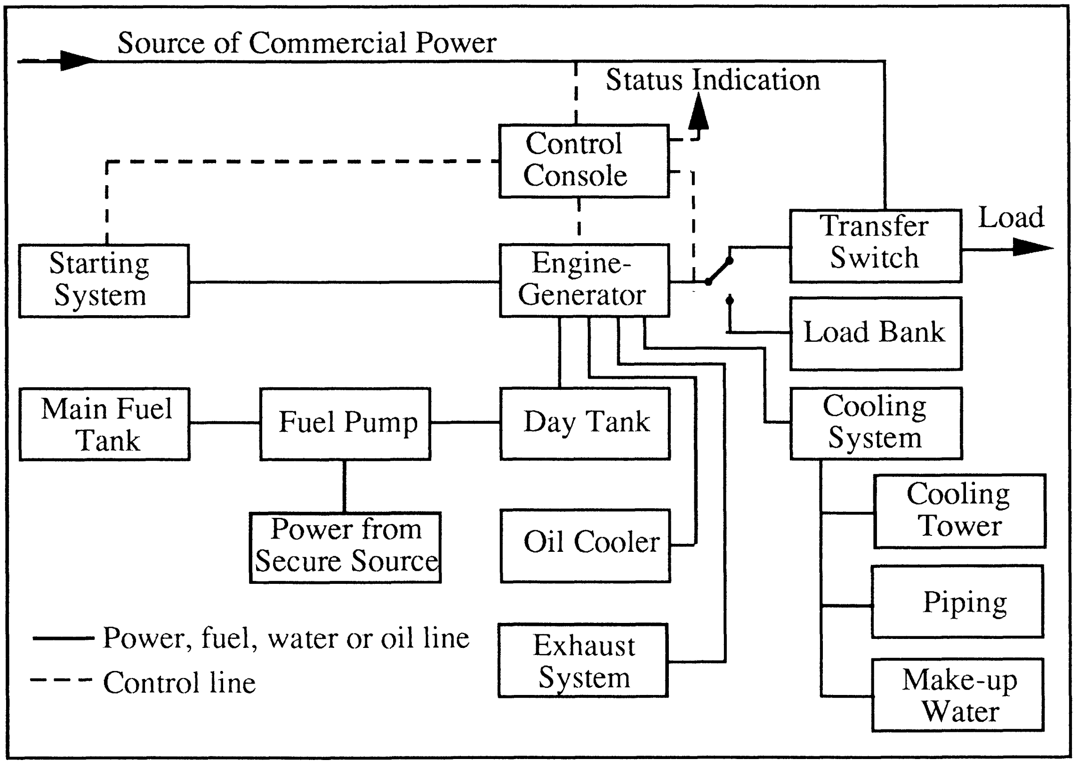

Figure 1 Components of a large engine-generator system

In light of the poor performance of emergency power systems, at least one large telephone company has installed external power hookups to most central offices to facilitate connecting a mobile engine-generator to the central office.

Emergency Power at Cell Sites

Wireless cellular telephones are used as a primary or alternative means of communication for some emergency service providers. In the aftermath of an earthquake many cell sites may loose commercial power. Most cell sites have a UPS system that can support operations for three to five hours. In metropolitan areas, cell sites are often located in tall office buildings in which engine-generators are not allowed because of potential fire hazard or noise problems. These sites are seldom provided with significant additional UPS capacity to supply power during longer power disruptions.

In the aftermath of a damaging earthquake it is often impossible to provide back up power to the numerous sites without emergency-generators that exhaust their UPS systems.

Performance Criteria

Stakeholders could probably arrive at an acceptable overall performance criteria for emergency power for central offices and cell sites. These criteria would probably establish a level of operation and duration of service that is to be provided by the emergency power for various facilities. The problem has been that the desire for reliable emergency power does not directly translate into equipment specifications, installation, operation and maintenance practices. Thus, in addition to overall performance criteria, detailed performance, design, installation, operation and maintenance practices will also be needed to meet the overall performance criteria.

Concentration, System Modeling and Telecommunications Performance

by

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Abstract

The overall performance of a telecommunications network is a function of the performances of its constituent layers, and lifeline earthquake engineering addresses mainly the physical layer. Contributions of lifeline engineering to physical performance are reviewed in this paper, and two areas are singled out for discussion: Lifeline interaction and concentration. Lifeline interaction, i.e., T/C failure due to disruption to its support lifelines, is deemed the most important cause of failure now that direct failure of equipment is unlikely. However, interaction is but a special case of concentration, which refers to all locales with an over-abundant presence of assets. Where there is concentration, the effects of a failure among the pool of assets are always amplified. It is submitted that concentration will become only more acute as current trends in technology and market competition continue, but this key driver of system performance can be assessed readily in a network model of the physical layer as part of the overall system model used by T/C engineers. It is argued that for the lifeline engineering community, the goal of performance assessment is the overall performance criteria per se, but improved performance at minimal cost/investment to the carrier and the public. Improved performance can be achieved (1) through closer interface with the T/C community and government agencies, (2) by jointly defining and quantifying a performance-measure hierarchy that accounts for the physical layer, and (3) by sharing of system assessment tools and methodologies that constitute an integrated and comprehensive approach covering all layers of the network.

Introduction

The performance of a telecommunications (T/C) network depends on many factors, notably hardware, software, configuration details and management approach. Technology is advancing at such a rapid pace, the number of players increasing and merging so quickly, and society's appetite ever so voracious that quantifying network performance is invariably a lagging task.

To be sure, the reliability of major T/C components such as the fiber-optic link or digital switch is high, far above standards of most infrastructure systems. For example, the end-to-end availability between two end offices 10 miles apart is of the order of 99.9986 percent (see Hou, 1991). However, T/C networks are also extremely complex, its underlying technology evanescent, and market forces and constraints have led to a myriad of configurations with various degrees of sophistication. These factors can degrade performance significantly when the network is under stress; it is easy for a few weak links to bring network reliability down from stratospheric figures.

Compared with other lifelines such as power, water and transportation, T/C has benefited the most from high technologies, but in doing so has become more esoteric to the general engineering community. Civil, structural, mechanical and electrical engineers have taken a back seat to T/C and network engineers; T/C as a "lifeline" simply entails too much knowledge outside the scope of traditional lifeline engineering. However, our supporting role is not unimportant, since mechanical and structural well-being of the T/C network and components, known as the Physical Layer in network terminology, is a basic part of the functional equation. Such support is essential when abnormal environmental conditions are encountered. When the Physical Layer is threatened, everything built on top of it is also at risk regardless of technological sophistication.

This paper first reviews how recent accomplishment in lifeline earthquake engineering have assisted T/C engineers in addressing network performance and their quest to establish reasonable performance criteria. Although the context of presentation is earthquakes, the discussion can be easily carried over to other natural hazards such as hurricanes and floods, and man-made hazards such as accidental release and terrorism acts. From such backdrop two aspects of T/C lifeline engineering are seen to distinguish themselves: Concentration and Network Modeling. Concentration, undesirable though it may be for reliability, is the inevitable result of current and future technology trends, the confluence of a number of independent developments. The need to evaluate concentration and other effects prompts the evolution of network modeling tools dedicated to the study of the robustness of the Physical Layer, so that they can be used, in concert or tandem, with mainstream network management tools to quantify system performance (and criteria).

The Physical Layer

Network engineers often refer to the Physical, Logical and Service Layers of a network in discussing system reliability; reliability of the network depends on reliability of the constituent layers. Table 1, taken from Taka and Abe (1994), is indicative of how the layers are perceived by that community and the quality measures associated with the respective layers. Note that "physical" components are not limited to the Physical Layer; for example, transmission equipment are considered part of the Logical Layer. Even with that taken into consideration, it is clear from Table 1 that quality measures extend far beyond what the lifeline engineering community can address. As illustration, Figure 1, also taken from Taka and Abe, gives a glimpse of the evolution of T/C technology and the countermeasures installed by network engineers to ensure network performance, with specific reference to the three layers of distinction.

Table 1. Typical Components and Quality Measures for Each Network Layer (from Taka and Abe, 1994).

Layer	Typical Components		Quality Measures	Issues
	Node	Link		
Service layer (provides voice/data/cell services)	Switches, STP, SCP	Trunks, data links, channels	Data integrity; traffic security; traffic throughput rate; blocking rate; cell loss; switching delay; service restoration time	Congestion control; dynamic routing; policing; arrangement of echo canceler; multipoint traffic dimensioning
Logical layer (provides transmission path)	Transmission equipment	Transmission paths	Path connectivity, bit error rate, transmission delay, system availability	Arrangement of CLAD; traffic shaping; application of node duplexity; route diversity; self healing
Physical layer (provides geographical diversity)	Buildings	Tunnels, ducts, cables, right-of-way	Number of surviving buildings/cables, availability	Geographical diversity; building location and size limitation; protection against disasters

STP: Signal Transfer Point
SCP: Service Control Point
CLAD: Cell Assembly and Disassembly

Lifeline engineering as it stands addresses mainly failures within and affecting the Physical layer and equipment, which we shall refer to together as the Physical Layer for convenience. While network engineers typically worry about equipment malfunction under ambient and adverse working conditions and rupture of links due to accidents or degradation, they do not as a rule contemplate wide-scale disruption to inside- and outside-plants such as caused by earthquakes. That role belongs to lifeline engineers.

T/C Performance in Abnormal Environments (Lifeline Engineering Contributions)

The goal of lifeline engineering is to improve system performance through better understanding of the abnormal environments in an extreme event, by quantifying the physical response of key components to such environments, and with improved designs of components and network. For T/C lifelines, a great deal of effort has gone into learning how failures occurred, and making the inside- and outside-plant components more secure (e.g., see Tang and Schiff, 1996). In general, T/C networks are very robust when the proper physical countermeasures have been taken, and seismic protection of T/C equipment and their installation have advanced to the point where direct failure of critical equipment is unlikely. Today, failure is more likely to be caused by collateral damage, e.g., to host building and loss of ground, and failure of supporting lifelines, e.g., loss of power, water, and through fire (see Wong and Isenberg, 1995). Furthermore, it is found that although the mechanisms of collateral and indirect failures are known, their effects depend on particulars of the site, and each site must be evaluated on a case by case basis.

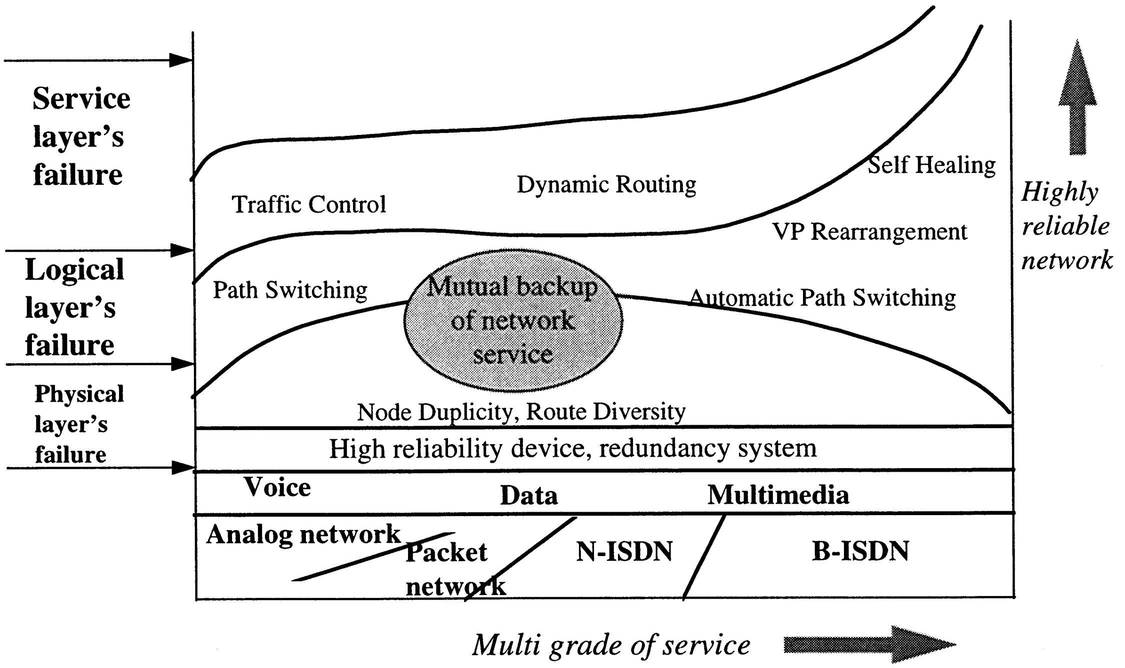


Figure 1. Evolution of network reliability countermeasures, circuit-switched networks (from Taka and Abe, 1994).

Component Fragility

Fragility of major T/C equipment have been tested and studied extensively by Bell Communications Research (Bellcore), regional Bell operating companies (BOCs), equipment vendors (such as Northern Telecom), and testing laboratories (such as Wylie Laboratories). With the advent of microprocessors and digital switching and transmission, T/C equipment have become ever more compact and robust although much of this progress has not been communicated to the lifeline engineering community due to proprietary concerns. An exception is a recent special project jointly sponsored by Bellcore, NSF and NCEER[1] and Table 2 depicts typical results that have been communicated by Bellcore. While these data are invaluable, it is equally obvious that given the torrid pace at which T/C technology is advancing, data such as Table 2 may already be outdated.

By contrast, less is known about outside-plant equipment such as fiber links, remotes and repeaters when they are subjected to extreme environments, except that fiber-optics cables are in general quite robust (Wenski et. al., 1989, and Setman and Brandtner, 1988). Japan is apparently the only country that has studied these components, no doubt because of extensive earthquake damage it has witnessed. Almost all of the damage to conduits and buried cables in Japan is caused by permanent ground displacement (Nakayama, 1991, Takada et. al., 1987, and Yagi et. al., 1991). The large variety of cable constructions, cable

Table 2. Sample Qualification Data From Bellcore (Switching Equipment Systems).

Generic Equipment Type	Earthquake Zone Tested							
	Conforming				Non conforming			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
SS-1						x		
SS-2								x
SS-3		x						
SS-4				x				
SS-5				x*				
SS-6								x+
SS-7				x				
SS-8				x				
SS-9				x				
SS-10				x				
SS-11								x

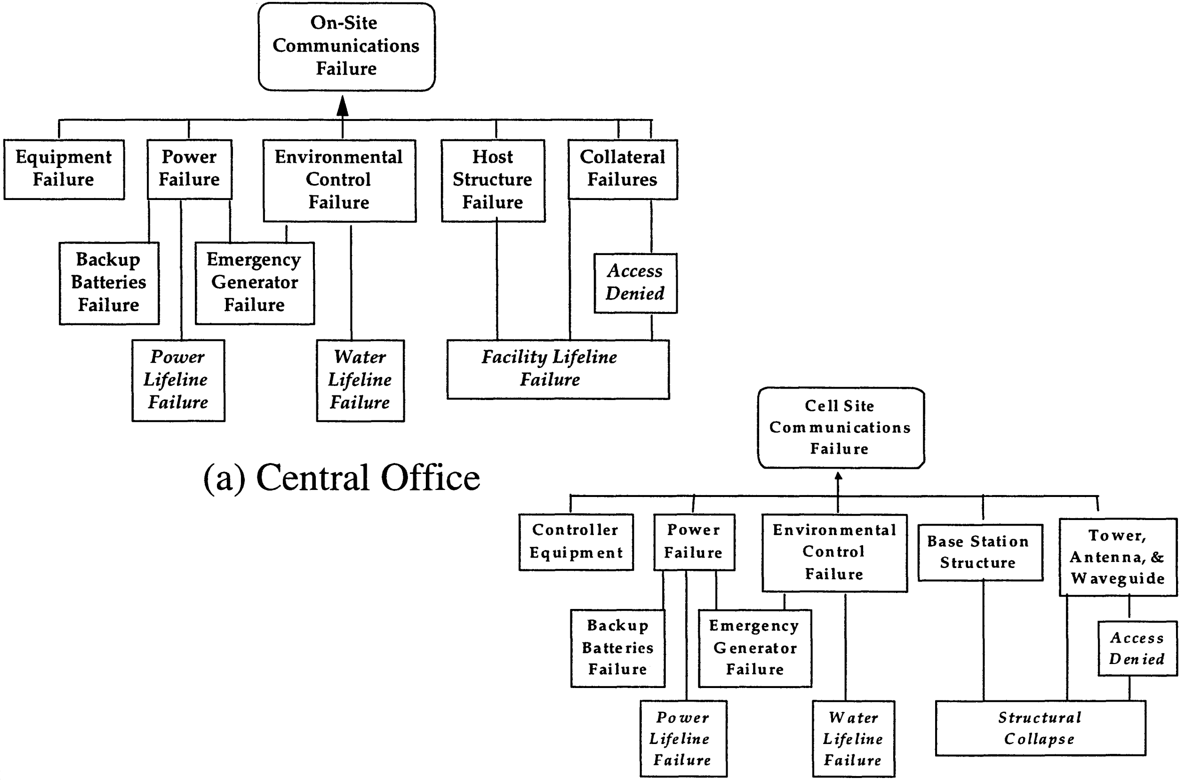
* Tested with special earthquake hardware.
\+ Non conforming, with overhead bracing.

types and placement methods, e.g., bare, in conduits, inside empty pipelines, can only add to the uncertainty regarding outside-plant equipment performance (Wong and Isenberg, 1992).

Host Structures and Function Support Systems

Drawing on its vast experience in building response and lifeline systems, the lifeline engineering community has addressed this portion of T/C systems fairly well despite a scarcity of direct data on damage (due to proprietary constraints and absence of major events in populous areas). Much of the mainstream know-how on seismic response of structures is applicable to central office buildings (COs) in metropolitan areas, which tend not to change much over the years. By and large, upgrades and improved bracing technology have been effective in reducing damage although structural damage to older COs is still common (e.g., see Tang and Wong, 1995, and Harris et. al., 1995, for findings on the Northridge earthquake). New facilities in newly developed areas tend to be even more robust because of better construction and usage, although commercial buildings are also being used for CO purposes as a matter of economics and convenience.

In contrast, function-support systems have changed little despite advances in our understanding of the fragility of lifelines systems such as power and water. Post-earthquake reconnaissance confirms that lifeline interaction remains a major liability (see Schiff, 1995). Failures of power and backup power systems, in particular, affect overall system performance at a site whether that site is a land-line office or cellular station. Damage to host structures (including supports and bracing) is also an important factor, but details vary depending on site specifics (see Figure 2). We call these effects lifeline interaction effects.



(a) Central Office

(b) Cellular Site

Figure 2. Lifeline interaction affecting communications performance, for a central office and a cellular site.

Lifeline Interaction or Dependency

In the context of network analysis, lifeline interaction or dependency is not limited to just the nodes. Interaction is important to the links as well, as evidenced by failures of T/C cables along transportation routes such as bridges, highways and easement. The complete scope of lifeline interaction can be summarized in Figure 3, where the effects can be attributed to functional, collocation or recovery dependency (Wong and Isenberg, 1995). It is clear that quantifying the effects of these dependencies for a complete network, even if confined to the Physical Layer, is a daunting task and a new approach is needed. This is described in the following.

System Assessment and Modeling Tools

To adequately assess the performance of a T/C network, the model must include all three layers of interest although by necessity we will confine ourselves to the Physical Layer. Even in this reduced role, the scope of performance assessment is huge as depicted in Figure 4. Recognizing the need to manage configuration and other data on multiple lifelines so that their interaction effects can be identified and quantified, a new generation of system modeling tools based on GIS (Geographic Information System) technology has been developed. For example, in TelSys (Wong and Isenberg, 1995), various geology, seismicity, hazards data as well as lifeline assets are built as layers and incorporated into the system with incremental effort. The geometric and spatial operations innate to GIS are exploited in processing the data layers. Engineering and decision modules that correspond to empirical and theoretical state-of-the-art knowledge in earthquake engineering are added as enhancement. Figure 5 depicts how layers corresponding to communications, water, power and transportation networks in a metropolitan area are aggregated and the effects of their disruption on communications, and one another, evaluated.

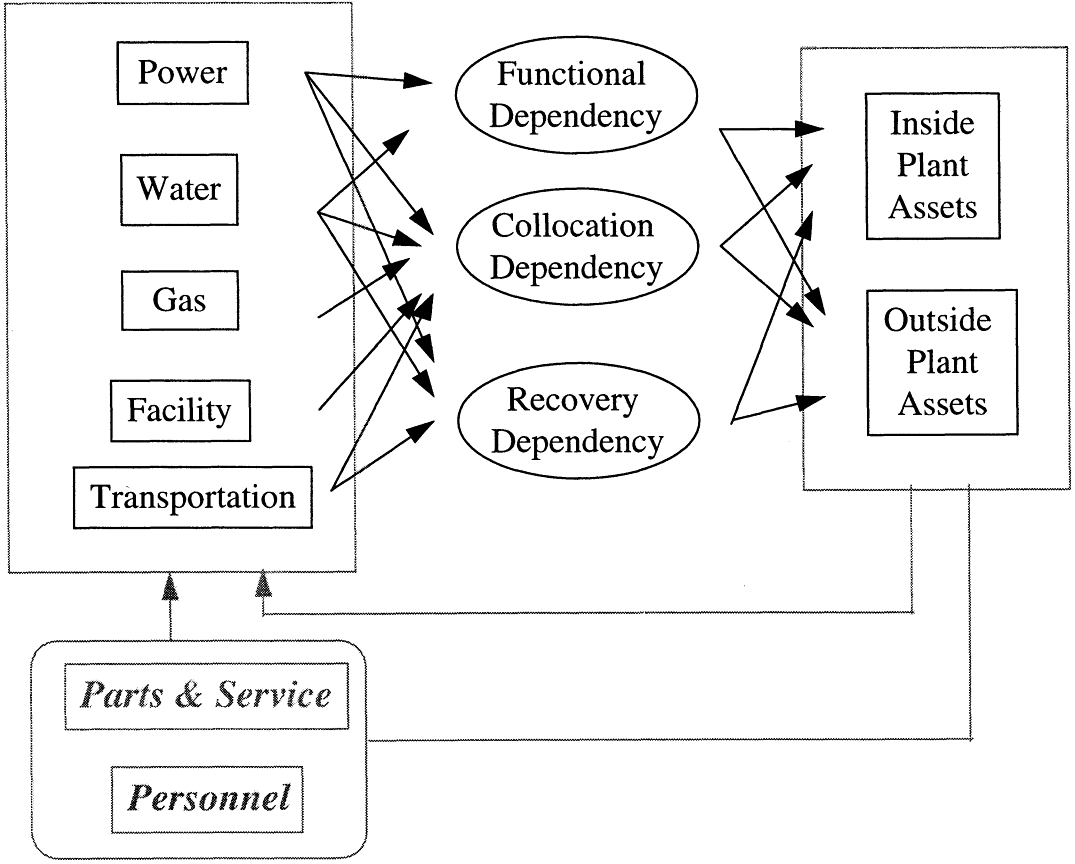


Figure 3. Complete scope of lifeline interaction and dependency effects on T/C performance.

Even with the help of GIS technology to relieve the burden of data handling and processing, a complete thorough interaction analysis is currently handicapped by several factors. They include absence of definitive fragility models on support systems (inside plants) and new outside-plant equipment (such as Controlled Environment Vaults). A lack of data on collocative interaction models, such as the relation between facility damage and office function reduction, is also hampering progress.

However, the most formidable obstacle to performance analysis is a matter of scale, size and resolution. It is acknowledged that lifeline performance cannot be evaluated except on the network level; the system is widely distributed, and the footprint of a seismic event is large. For example, many small leaks in water pipes over a significant area can completely drain the water pressure. At the same time, local concentrated damage is also

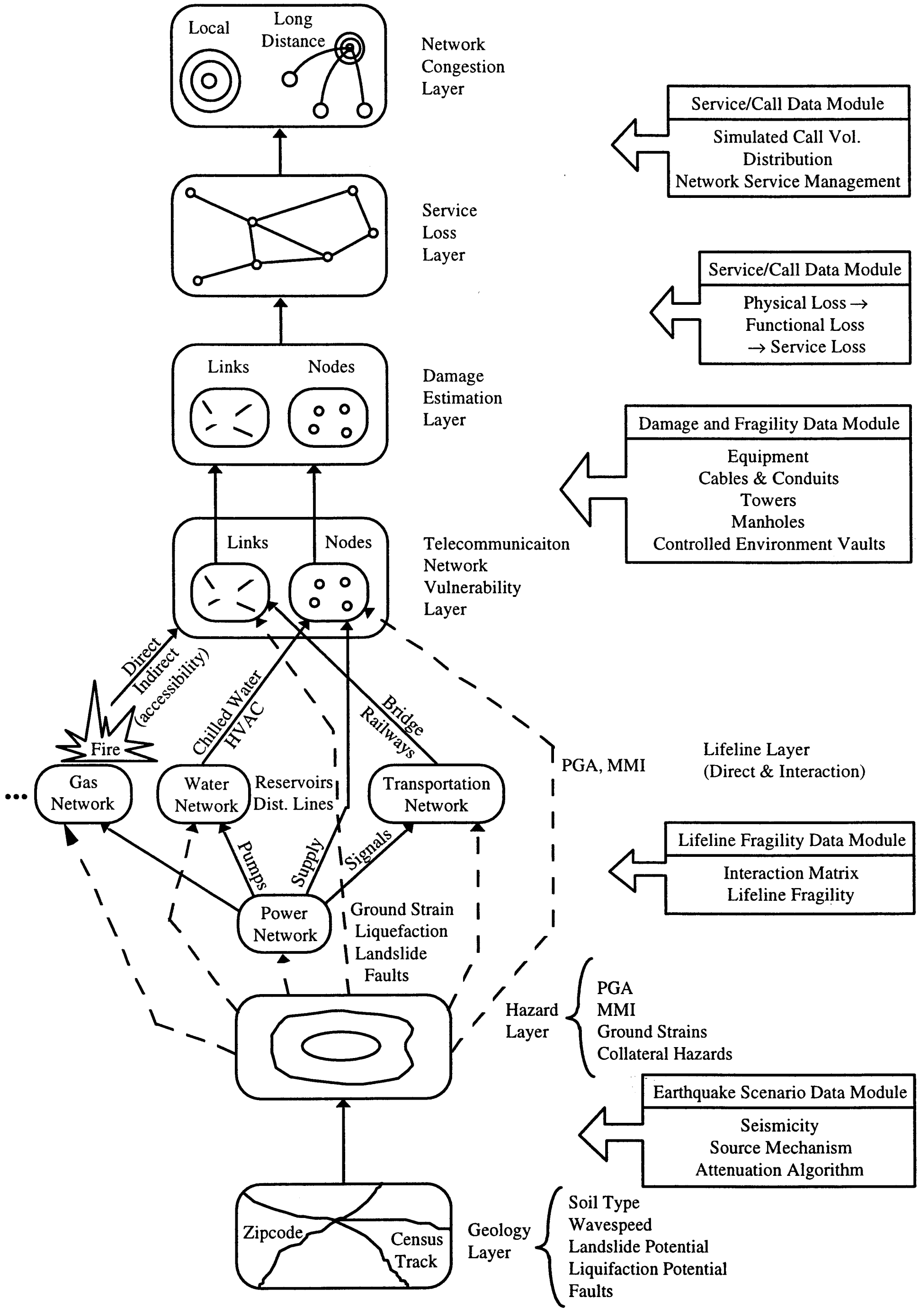


Figure 4. Network performance models, with emphasis on the Physical Layer and lifeline interaction effects.

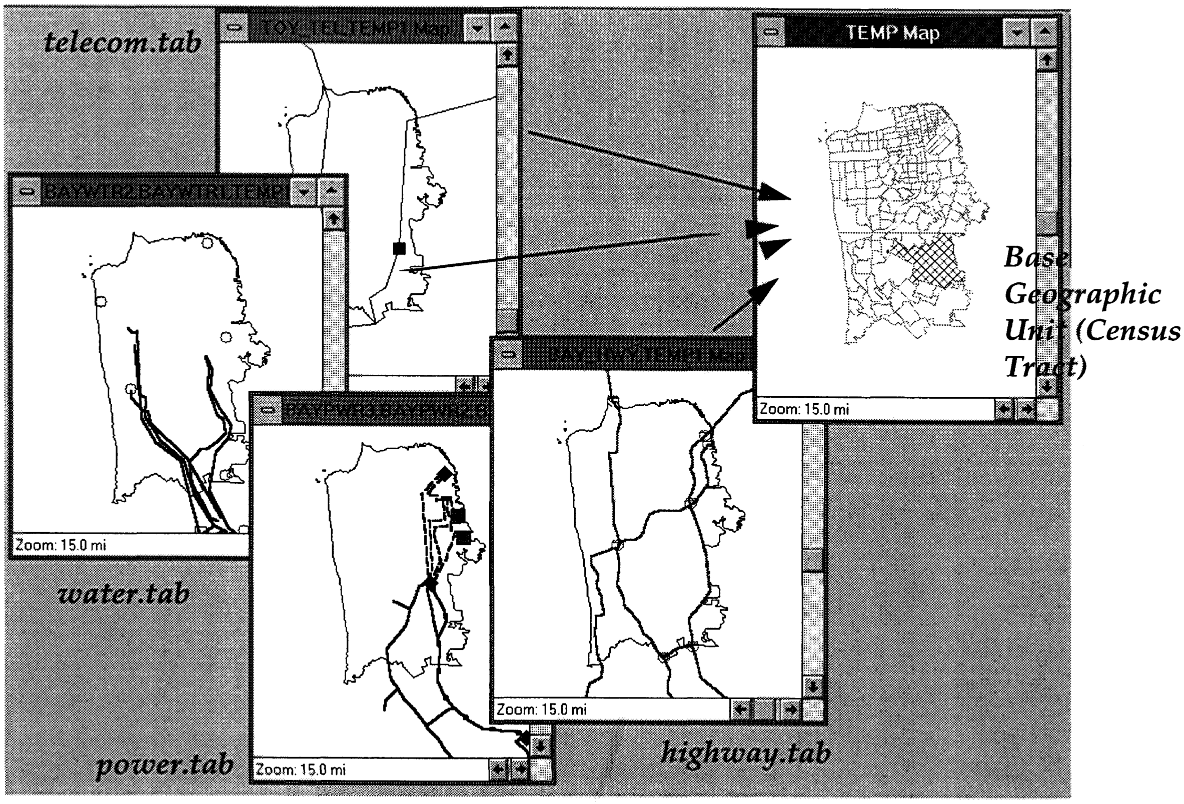


Figure 5. Aggregating multiple and damaged lifelines to estimate their interaction effects on T/C performance.

important such as the failure of a substation or a dam. Lifeline interaction must also satisfy these opposing requirements. The models must contain sufficient local details for "point" interaction, and sufficient regional details to account for "distributed" interaction at the network level. Even if the prerequisite data were available, the demand on computing resources would be too great for such task to be practicable.

A resolution of this dilemma is by emphasizing the "hot spots" in modeling. Hot spot denotes a location or area that is more important than others, and may manifest itself in a wide variety of objects. For individual lifelines such as power, a hot spot would be the nearest substation or generation plant that has failed. For a pressurized water distribution, a hot spot would be a failed pumping station, and so on. In the context of T/C and its interaction with support lifelines, a hot spot is invariably a location of high concentration, and is discussed in the following.

T/C Concentration

Concentration is used as a geometric term and denotes an over-abundant number of assets at one locale, or, too many eggs in one basket. It is the opposite of diversity or distributiveness. Though commonly acknowledged as undesirable, concentration in T/C is invariably the result of technology and business trends. These considerations as summarized below often take higher priority, pushing reliability to the background.

Equipment Advances (Technologic)

Examples are higher bandwidth and ever greater number of fibers that can be accommodated in a cable, and increasingly compact microprocessor-based switches with smaller footprints. Hence, more traffic can be routed and switched within the same space, and the natural tendency is to make maximum use of space. One office can serve as several offices.

Access and Cost (Economical)

T/C are often routed along side other utility lines, i.e., railroads and highways, because of easement privilege and access. Hence, there is not only T/C concentration, but concentration of other lifelines inviting interaction effects.

Network Configuration (Topologic)

A network architecture that can best utilize the economics of high-capacity fiber systems and reduce the amount of equipment needed for signal transport is the hub-and-spoke (Figure 6). In this architecture, hubs are naturally more important and more concentrated than offices on the spokes. A net configuration, by contrast, is more expensive but affords more diversity.

Carrier Interface (Relational)

For some time after deregulation, the interface between local-exchange and inter-exchange carriers follow the paradigm as shown in Figure 7. An IXC (inter-LATA exchange carrier) connects between LEC (local exchange carriers) access networks, which in turn connect to the customer location. Each network has a core section with high connectivity, and edges with typically less connectivity that reach a boundary. In particular, the legal/administrative interface between an IXC and LECs is the Point of Presence or POP. By their very nature, POPs are singular points that join networks together. Whereas the joined networks may have high redundancy and diversity within themselves, POPs are points of concentration. Loss of a POP may completely severe the tie between an inter-exchange carrier with its local-exchange, and communications must be rerouted through another POP miles away.

Geographic Constraints (Topographic)

In other cases, there may simply be no other economically viable options for placement. For example, T/C assets in the San Francisco Bay area are concentrated along the population routes along the Bay as well as access routes across the Bay, viz., bridges (see Figure 8). Failure of the bridges has been known to threaten the T/C cables.

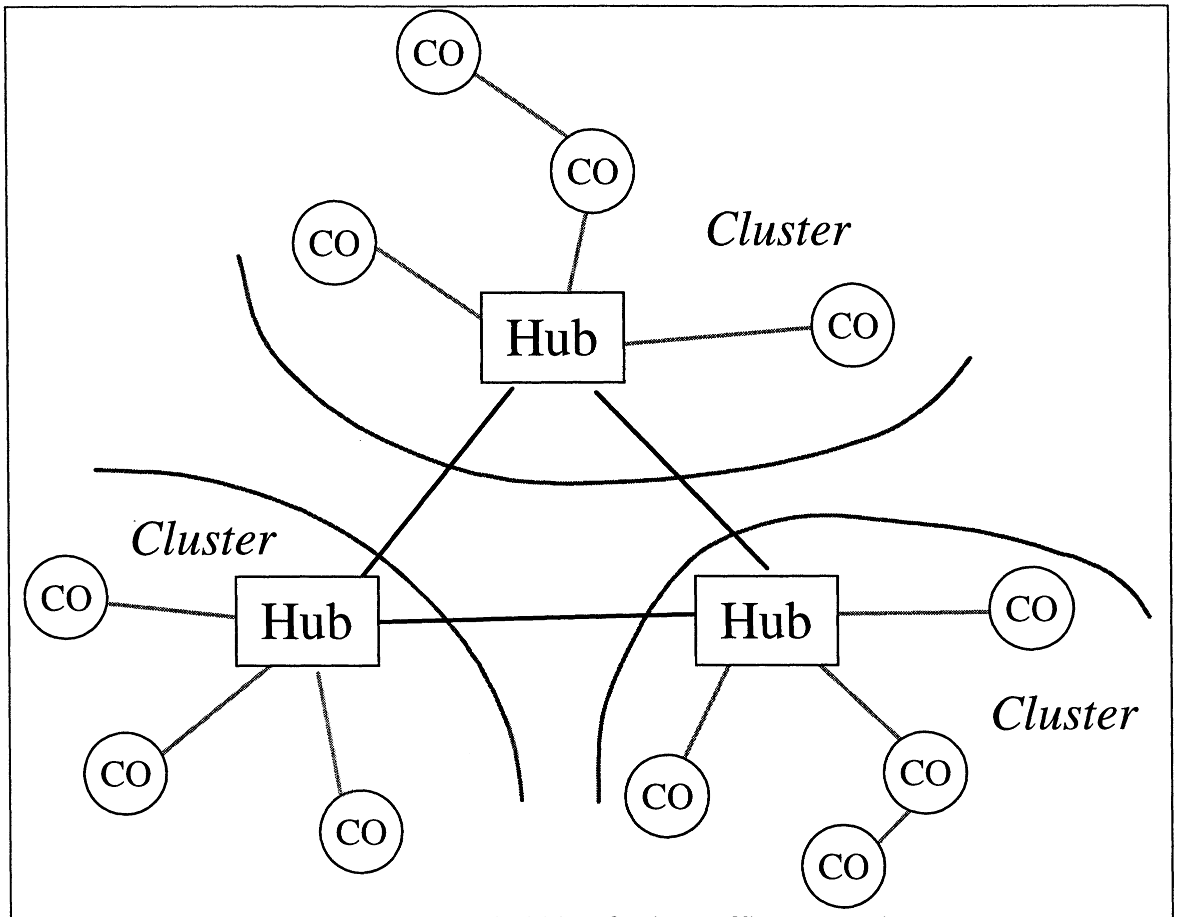
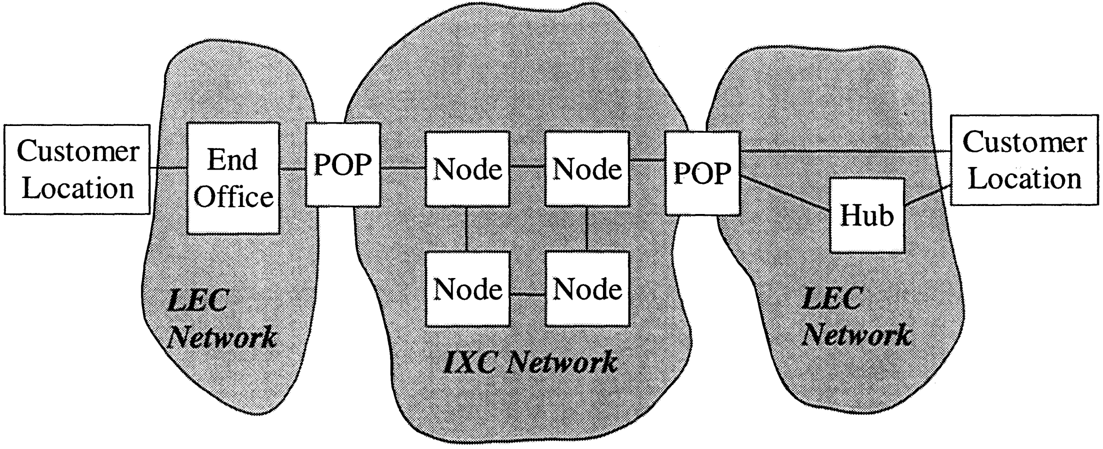


Figure 6. Facility hubbing for interoffice networks.



POP = Point of Presence
LEC = Local Exchange Carrier
IXC = Inter-LATA Exchange Carrier, or IEC
LATA = Local Access Transport Area

Figure 7. End-to-End customer connection through LEC, POP and IEX.

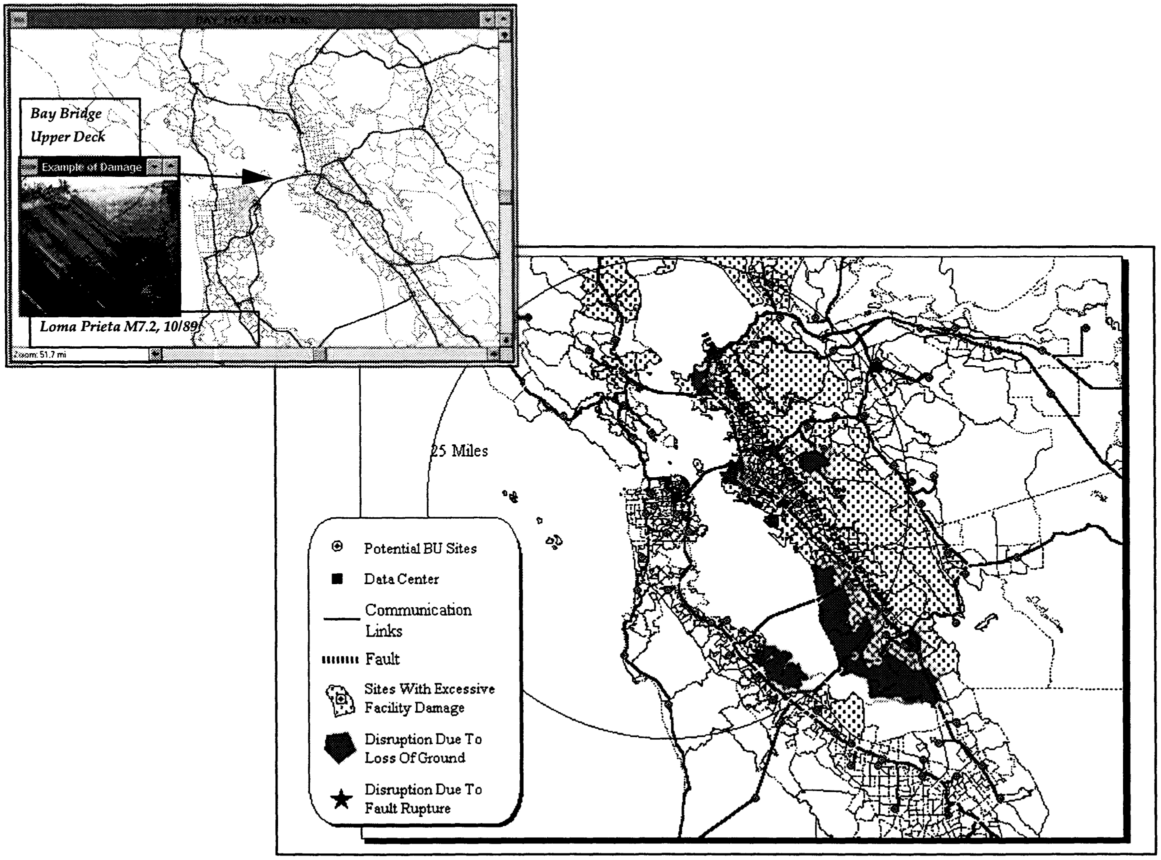


Figure 8. Concentration due to geographic and topographic constraints.

Convergent Networks (Megatrend)

Perhaps the most significant impact on concentration is the potential development of the so-called convergent networks in the next decade. By combining the economy and advantage of the computer and Internet Protocol, these "convergent" networks can carry voice, data and video on the same line and at a much lower cost (Figure 9). Packet switching will enable voice calls and data be sent mixed in, at a much higher speed and over the same trunk line since the packets are more compact (as small as 8 kilobits compared with those of the standard voice circuits at 64 kilobits).

By most estimates, the new networks can carry six to ten times the traffic on traditional circuit-switched networks, while its cost is less than 10% of the price of traditional lines. The network equipment will be different from those of circuit-switched networks, and much less expensive also. To lifeline earthquake engineering, these developments represent the second quantum jump in concentration of traffic (the first being the transition from twisted pair and coaxial to fiber optics), and a new generation of more compact computer-controlled equipment.

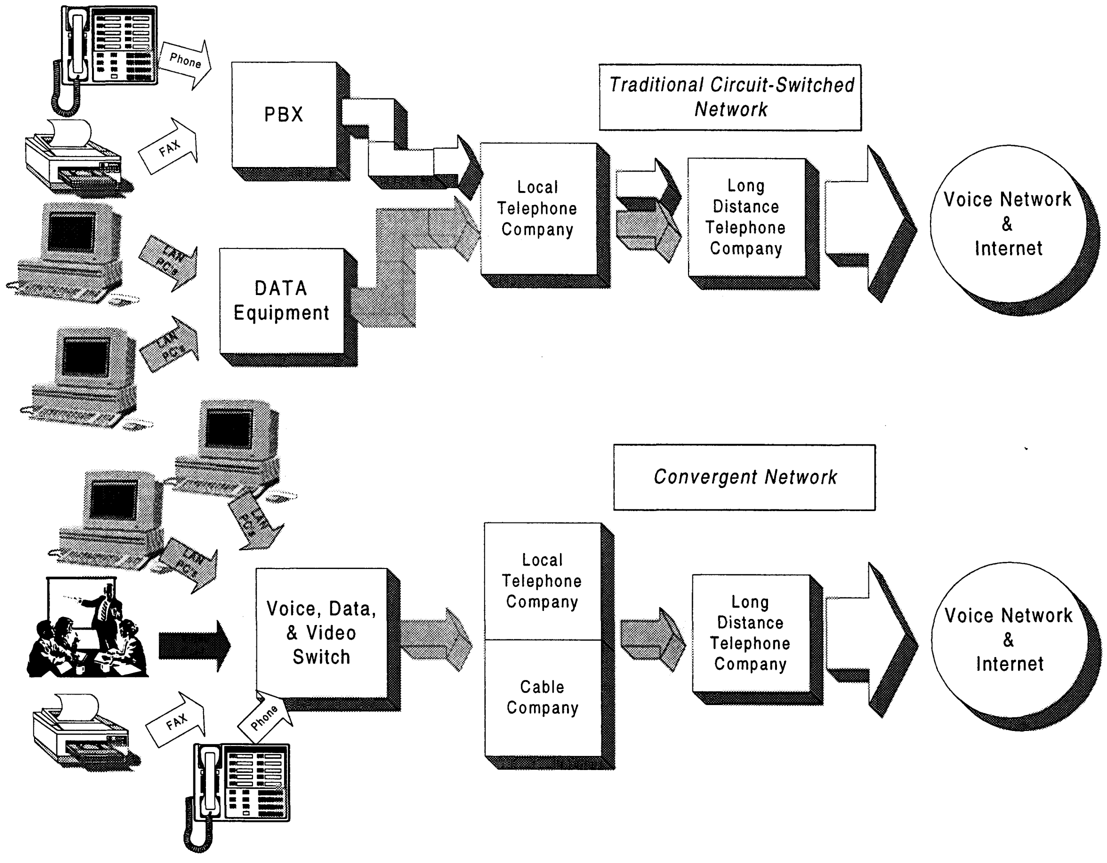


Figure 9. Comparison of data-based convergent networks and traditional voice-based circuit-switch networks.

Improving System Performance

Maintaining T/C performance during an extreme event, natural or otherwise, is not simply a technological and engineering issue. It is also an economic issue. T/C networks are often compared with highways. The latter are not designed by using peak traffic as the norm; delays and congestion for a brief period of time each day are accepted as the price for keeping the infrastructure cost down. As the saying goes, not everyone will be on the road at the same time every day.

Similarly, it is unusual that all customers will be calling at once, such as in the aftermath of an earthquake. Call saturation is and could be expected as the tradeoff for reasonable normal rates. Customers (governments included) with special requirements make special arrangements with the carriers, e.g., call priority, private lines and dual homing; they pay for the added service so that the cost is not passed to the public. Major corporations such as banks and utilities build their own private networks for better control. Hence, performance criteria vary with the customer.

To be sure, network capacity will grow as technology and competition pressures dictate. However, given the laws of economics, capacity will remain much lower than what could accommodate all users simultaneously. Performance will continue to be a bartered commodity. In this environment, improved performance at minimal cost or investment to the carrier and the public, may be the real (pragmatic) goal. Improved performance can be facilitated by more interchange and closer interface between the lifeline engineering community, the T/C community, and responsible government agencies.

We see fruitful interaction in the following manner:

- Transfer of results from lifeline engineering research in quantifying the abnormal environment (that threatens the Physical Layer) to the T/C community.
- Working jointly towards the definition and quantification of a performance-measure hierarchy, with the aim of separating out the performance measure for the Physical Layer if possible.
- Sharing of system assessment tools and methodologies for an integrated and comprehensive approach to performance assessment covering all three layers. For example, TelSys can be hooked to various network simulation software such as BONeS DESIGNER, COMNET, NETWORK and OPNET, just to name a few.

In the near term, we believe that lifeline-engineering research should focus on concentration and interaction, as they have the best payoff in enhancing performance. The hot spots can be readily identified, and what-if studies performed using, say, a tool such as TelSys, to weigh the cost benefits of potential countermeasures. While such work will still be restricted to the Physical Layer, the results can serve as prototypes of what the lifeline engineering community can offer, in quantification, to the T/C community, and, of what form or shape the feedback should be in return.

T/C is a $600 billion industry, and whether one likes it or not, its future will continue to be shaped by economics, competition and technology. With new players added every day, the public switch network (PSN) will continue to metamorphose into something that will be quite different from what it is today. The emergence of the convergent networks is just one example. Dedicated voice trunks and PBXs will be a thing of the past. Services such as voice operation, video conferencing, additional bandwidth (multiple lines) and multi-directional, multimedia communication will skyrocket as a convergent network made them much more affordable than twisted-pair phone lines.

What makes all-in-one networks so inevitable is that they are best in carrying data traffic, which is increasing 100% annually, while accommodating voice calls at the same time, which is growing only about 8% a year. Traditional phone (voice) systems were not designed for transporting data; they were designed for 3-4 minute phone calls and 30-minute connections to the Net tie up the system, whereas holding time is not a problem for data transfer. By most estimates, up to 10-15% of the world's phone calls could be carried over Internet-type networks by 2002, and the U.S. phone system will switch over to the new networks in as little as 10-20 years[2]. Voice-over-Internet equipment could reach $13 billion, and while the result of competition between traditional equipment manufacturers and upstart networking companies is too early to tell, a completely new generation of T/C equipment will be expected. Their seismic performance will need to be ascertained.

Summary and Conclusions

In summary, the lifeline engineering community should recognize the market and technology forces in planning our role and goal related to system performance criteria. We have more to offer in addition to our knowledge of the mechanical response of the physical components under abnormal environment. Specifically, we can contribute, in a supporting role, our understanding of network performance in the Physical Layer. In particular, two aspects of (physical) network performance are deemed most relevant: Lifeline interaction and concentration effects. While quantitative measures of these effects can be made given the state of the art in lifeline modeling tools, if only approximately, the results by themselves are insufficient to determine the overall system performance. Vulnerability of the Physical Layer is only the starting point for the Logical and Service Layers of the system, which are the domains of the T/C and network engineers. Secondly, changes in the T/C industry are fast and furious. It behooves us to anticipate industry trends and factor them into our plans, so as not to be outdated even before we start.

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Measures of Performance for Emergency Response Communications

by

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Abstract

The convergence of digital communications techniques makes necessary an encompassing view of telecommunications in emergencies. Such a view crosses technological, industrial, disciplinary and jurisdictional boundaries. A framework for characterizing the overall performance of the complex telecommunications network of the present and future is proposed. Such a framework is necessary to describe and pursue technical and policy goals for emergency response communications.

Introduction

This is a discussion of possible measures of telecommunications system performance from the point of view of emergency management practitioners. While its immediate focus is on earthquake response, the metrics proposed are meant to be widely applicable. It should be stressed that these metrics are intended for description of overall telecommunications system behavior, and not for prescriptive or regulatory standards of performance for particular systems or industries.

The Impact of Digital Convergence

Historically, evaluation of emergency telecommunications has been complicated by the variety of systems and technologies involved. Each system has been discussed separately using specialized models and vocabulary. No comprehensive view has been possible.

The trend toward representing all types of communication in digital form has led to greater interoperability among networks. Increasingly, voice, image and data links can be forged using any available facility or combination of facilities.

This has made discussions of telecommunications systems more complex since traffic can now move easily across traditional technological and industrial boundaries: from wireline to cellular telephone, for example, or from telephone to the Internet and back again. But it has also enabled users, including the emergency response community, to fuse diverse modes of telecommunication into a more flexible, robust and effective whole.

This convergence has made it possible (and necessary) for us to begin to view the aggregate of our telecommunication capacity as a single system. The assumption of essential boundaries between radio and telephone systems, for example, or between satellite and terrestrial communications, is breaking down. We have begun to see such divisions as merely vestigial inefficiencies in an otherwise-unified telecommunications environment.

Many of the telecommunications shortfalls experienced in earthquakes and other emergencies can be understood in this light: not as technological breakdowns, but as systemic failures which result from limited ability to shift communications traffic from impaired or overutilized facilities to underutilized ones. Much of the procedural and organizational overhead of emergency communications practice – message formats and coding, "message centers" and so on – has evolved to work around this sort of "soft" communications failure.

The metrics suggested here, therefore, are meant to be independent of particular technologies, and useful both for particular systems and in holistic models.

An Outer Framework: Space and Time

Most aspects of telecommunications vary geographically and over time, especially in a disaster.

For example, local saturation of cellular telephone and tactical radio channels is common in the immediate vicinity of major public-safety incidents. On the other hand, even in the midst of a disaster of the magnitude of the 1989 Loma Prieta Earthquake, telephone congestion in the impacted and affected areas showed a pronounced daily pattern reflecting morning and afternoon traffic peaks with improved availability at night.

Further, any communication depends on conditions at the endpoints and also those affecting intermediary facilities (switches, trunks, satellites, etc.) For example, calls between telephones within an impacted area may be impossible while calls to the outside succeed, or vice versa.

For purposes of describing telecommunications during and after a disaster it may be useful to represent geography in three zones:

- **Impacted** – The area suffering direct physical effects of the disaster (where emergency response operations are conducted).
- **Affected** – The larger area suffering immediate but indirect effects (e.g., disruption of utilities, transportation and commerce.)
- **Outside** – The rest of the world.

This would permit us to represent the telecommunications situation at any point in time within a 3x3 matrix representing the possible combinations of endpoints:

To: From:	**Impacted**	**Affected**	**Outside**
Impacted			
Affected			
Outside			

This arrangement would allow some consideration of asymmetry in traffic patterns: e.g., the volume of telephone calls into the impacted area from the outside versus outbound, or the use of broadcast technologies.

The third dimension of this matrix, time, might be divided into intervals as large as possible without loss of significant information. In general, intervals of three or four hours might be suitable. During the first hours after an earthquake or during other highly dynamic periods a finer resolution (single hours or even quarter-hours) might be useful.

Measures of Performance

The key to devising a useful set of metrics will be balancing the need for simplicity with the need for measurability. If we make them too specific and technical, the policy and practitioner communities will be excluded from the discussion. If we make them too broad and subjective, though, we risk losing our grasp on reality.

From a point of view somewhere between that of responders and that of telecommunications engineers, four broad aspects of telecommunications performance might be meaningful within a geographic and temporal framework as described above:

- Availability
- Capacity
- Quality
- Latency

Availability

In geographic terms this includes such concepts as coverage area, “footprint” and outage areas. In temporal terms it covers both long-term (provisioning/restoral), mid-term (outages) and short-term (blocking) events; viewed statistically it relates to grade of service, mean-time-between-failures (MTBF) and mean-time-to-repair (MTTR).

Within the space-and-time matrix proposed above, this aspect might be expressed as a percentage representing the probability that a particular communication path will be available during the period (grade of service). Particularly for the impacted area, it might also be presented in the form of geographic maps.

Where effective message-priority schemes are available, it may be useful to consider availability at different priority levels separately. However, prioritization schemes are only workable among users who hold a fairly homogenous set of values. As a result, there are limits to their significance when considering communications infrastructure in any broad context.

Capacity

This refers to the aggregate information-transfer rate available, and that needed, between areas during a period. Both of these might be expressed in multiples of bits-per-second, including equivalent values for analog communications based on the state of the art for digital transmission of the same content.

Available capacity generally remains roughly constant during short periods, with occasional "jumps" up or down as facilities go online or offline. Required capacity, on the other hand, may vary rapidly and continuously. (Note that we refer here to the theoretical demand for telecommunications – potential traffic – not to actual observed traffic, which is limited by availability and available capacity.)

It may be useful to describe both available and required capacity (and maybe also their ratio) as peak-and-average pairs, or graphically, or even in statistical terms.

Naturally, these values relate to others. Some communication systems (e.g., many data networks) accommodate excess traffic at the cost of increased latency (see below.) Others (e.g., the PSTN) block excess traffic, in which case excessive demand means reduced availability.

Also, some systems (mainly data networks) exhibit non-linear increases in load during periods of heavy use as a result of automatic retransmissions subsequent to network "collisions." This should remembered when extrapolating from user traffic data.

Quality

This refers to the accuracy with which messages are delivered to the receiver. Reduced quality can be experienced as distortion, as noise, or as data errors.

Quality is frequently described in terms of bit-error rates. Achieved quality might be described as peak-and-average (or "minimum-and-average"), in graphic form, or in statistical terms. (For wireless systems it might also be presented in geographic terms in the form of grade-of-service maps.) Again, analog measurements might be converted to digital equivalents for comparison.

As with capacity, variations in quality can be reflected in other parameters. When reduced quality results in repetitions and retransmissions, it can result in increased traffic. In severe cases quality is so poor it prevents the establishment of communication, in which case the effect appears in measures of availability.

Latency

This refers to time delays in the transmission of information over a communications system. Three types of latency can be significant, particularly in data systems:

- **Circuit** – The time required to establish a connection between two parties or nodes (for example, delayed dial-tone or slow call completion on the PSN.)
- **Message** – The time required to forward a message or transaction from sender to receiver (e.g., delivery time in email and EDI systems.)
- **Data** – The time required to transmit a packet of data from sender to receiver (as in those annoying delays on satellite telephone connections, or during traffic peaks and malfunctions on the Internet.)

Each of these forms of latency can be described in terms of peak-and-average times. Circuit latencies will typically be measured in seconds, and data latencies in milliseconds, while message latencies may range from seconds to hours depending on the system involved.

Latency is frequently a system-specific parameter, but it still has a number of uses. Circuit and data latency can help characterize key differences between circuit-switched systems such as the PSN and data-switched systems including the Internet and other data networks. Message latency might even be used in high-level models of overall communications effectiveness. All forms of latency can have serious impacts on time-sensitive and high-volume communications.

Conclusion

By reducing the complexity of telecommunications metrics to a few key dimensions we can enable a useful conversation among the technical, policy and practitioner communities. Such a common framework can reflect the geographic and temporal dimensions of disasters and the essential performance characteristics of all telecommunications facilities. It can serve as a point of departure for investigation of issues such as “technological diversity” strategies for resilient communications, and as a factor in broad-based studies of the indirect economic and social costs of earthquakes and other disasters.

Telecommunications Performance Modeling: Data Collection Needs and Issues

by

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Abstract

Mathematical models of the performance of telecommunications systems are required for designing protective measures to prevent communication service problems and for responding rapidly to those that do occur. Certain basic data describing observed earthquake effects is needed to develop and validate these telecommunications models. Yet the telecommunications industry does not routinely release such data, considering it proprietary and/or sensitive. This paper defines the basic data needs, identifies data availability issues, and proposes resolutions to them.

Introduction

Mathematical models of the performance of telecommunications systems are required for designing protective measures to prevent communication service problems and for responding rapidly to those that do occur. Telecommunications design engineers need the models to predict or estimate where and how disruptions to telecommunications services in their networks are likely to occur in order to design measures to prevent them. Emergency response personnel need the models to predict or estimate the extent of the telecommunications disruption to the population and to the emergency responders themselves. Certain basic data describing observed earthquake effects is needed to develop and validate these telecommunications models. Yet the telecommunications industry does not routinely release such data, considering it proprietary and/or sensitive. This paper defines the basic data needs, identifies data availability issues, and proposes resolutions to them.

Data Collection Needs and Issues

This section is divided into two subsections: (1) an identification of basic data collection needs at end offices, local tandem offices, and interexchange offices; (2) an identification of the issues surrounding data collection and proposed resolutions to those issues.

Data To Be Collected To Develop/Validate Network Performance Models

The following data needs are not intended to represent a complete set of data requirements to build telecommunications performance models. Rather, the data needs identified are focused on the data required to validate the predictions or estimates from such models and to ensure their usefulness to telecommunications engineers and emergency responders.

- For each local end office:
  - Number of customer call attempts not completed vs. total call attempts
  - Number of customers without service vs. total number of customers
  - Service outage duration
  - Is lack of service due to:
    - Local loop damage
    - End office damage
    - Call Overload
    - Deliberate Call blocking
- For each local tandem office:
  - Number of interoffice trunks out-of-service vs. total trunks
  - Service outage duration
  - Call carrying capacity of out-of-service trunks vs. total call carrying capacity
  - Is trunk service outage due to:
    - Trunk damage
    - Tandem office damage
    - Call Overload
    - Deliberate Call blocking
- For each Interexchange (Long distance) office:
  - Number of customer call attempts not completed vs. total call completions
  - Number of customers without service vs. total customers
  - Service outage duration
  - Is call non-completion due to:
    - Transmission route damage
    - Interchange office damage
    - Call Overload
    - Deliberate Call blocking

Issues In Collecting Data

- Most of the data needed, as described above, is not publicly released by the telecommunications carriers since they consider it proprietary or sensetive

- Some/much of the above data should be available at the Federal Communications Commission (FCC) due to mandatory outage reporting rules in effect since 1993:

  - Outages must meet certain criteria e.g., end offices must be out for at least 30 minutes and serve at least 30,000 customers

  - The ATIS Network Reliability Steering Council (NRSC) maintains similar data in its database and issues quarterly reliability reports
  - Earthquake lifeline engineers should seek data from the above public domain sources as the first source of data
- The remaining basic data is considered proprietary by common carriers and will generally not be released
  - Earthquake lifeline engineers should offer to sign non-disclosure agreements with individual carriers in order to obtain data; a letter from FEMA, NSF, TCLEE, etc. stating the need for the data would also assist in opening some doors

GETS Provides Critical NS/EP Telecommunications Connectivity During Emergencies

by

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Abstract

The Government Emergency Telecommunications Service (GETS), a service of the allows the National Communications System (NCS), to provides nationwide voice band services for authorized government users engaged in National Security and Emergency Preparedness (NS/EP) activities. Taking advantage of the vast resources of the public switched network (PSN), GETS provides emergency access and specialized processing in local and long-distance telephone networks, ensuring users of a high rate of successful call completion during network congestion or facility outage arising from natural or man-made disasters. Emergency responders within a disaster area need onlyto access an in-service public or private telephone to receive the benefits ofaccess GETS. Results from analytical studies indicate a very high likelihood probability of GETS call completion for both high congestion and also equipment outage accompanied by high congestion conditionsduring extreme congestion or extensive damage within the PSN when all switches in the call path are provisioned with planned GETS improvements. This compares to a very low likelihood of plain old telephone service (POTS) call completion for the same conditions.

Background

The Government Emergency Telecommunications Service (GETS) was established by the Office of the Manager, National Communications System (OMNCS) to meet White House requirements for a survivable, interoperable, nationwide voice band service for authorized government users engaged in National Security and Emergency Preparedness (NS/EP) missions. GETS satisfies these requirements by providing emergency access and specialized processing in local and long-distance telephone networks. This ensures users of a high rate of successful call completion during network congestion or outage arising from natural or manmade disasters.

From the beginning, GETS planners focused on the public switched network (PSN) as the most efficient, reliable technology for supporting a service which would meet the

NS/EP mission requirements. The use of the PSN offers the advantages of the vast resources of the PSN--, a $300 billion infrastructure with over 150 million access lines and 25 thousand switches. As a strong survivability plus, the PSN contains redundant hardware and extensive self-checking and recovery software. Use of the PSN also capitalizes on the fact that the PSN is ubiquitous, robust, and flexible, and supports 95 percent of the Governmentís telecommunication needs. And, despite its enormous size and complexity, the PSN averages 99.999 percent availability or better.

The initial objective was to expeditiously field a service that would provide emergency personnel with priority call treatment and to gradually improve the service with specialized calling features. The strategy to develop GETS using existing assets of the PSN enabled early implementation as well as provided technical currency by leveraging the continual improvements made by the industry. Utilizing the resources of the PSN would also circumvent the needmade it unnecessary for the Government to purchase, installation, maintainenance and eventually updatieng of network equipment.

A modular implementation approach was followed for GETS to accommodate the dynamic characteristics nature of the effort. Specifically, GETS is being implemented in phases and each phase is a service in itself. Thus, if future modules are not built, those already implemented will continue to provide a useful service.

The approach to implementing and evolving GETS initially focused on the interexchange carrier (IEC) portion of the network with implementation in the local exchange carrier (LEC) portion now currently receiving primary attention. This approach resulted in separate GETS contracts with AT&T, MCI, and Sprint. Each IEC began with the same basic set of functional requirements.; Hhowever, as a result of the implementation approach pursued by each IEC and the inherent differences in the structure of their respective networks, the operational features and capabilities differ somewhat among the providers. In addition, a separate contract was competitively awarded to GTE Government Systems for integration of LEC implementation of GETS and for overall GETS operation, administration, and maintenance services.

The phased implementation approach has proven to be quite successful. The phases, designated as Limited Capability (LC), Initial Operational Capability (IOC), and Full Operational Capability (FOC), are described briefly below.

- The **LC phase** began on 30 September 1994. Throughout this phase, users were able to place GETS calls through the LECs, using the universal GETS access number, to the three IECs who provide GETS call processing.
- The **IOC phase** began on 1 October 1995. IOC consists of all LC capabilities as well as additional IEC services. The Government is in the process of issuing task orders to implement GETS services in the LECs based on the results of a LEC Service Engineering Analysis done under the IC Contract.
- The **FOC phase** is scheduled for the year 2001. Additional capabilities may be included at FOC based on the results of other IC analyses that demonstrate the benefit of such capabilities.

Emergency Conditions

Many crisis situations cause the PSN to experience abnormally high traffic levels or loss of network capacity, preventing emergency personnel from completing calls. These situations include network failures, natural disasters (e.g., hurricanes, earthquakes, etc.), and manmade disasters (as in the case of a fire, cable cut, software problem, or terrorist act). While failures in switching or transmission system elements can isolate a large portion of the network, disasters can result in damage to network facilities or stimulate extraordinary levels of calling. Between 1989 and 1996 there were an average of 37 major disasters and/or emergencies per year designated by the President for receipt of Federal Emergency Management Agency (FEMA) aid. These and state declared disasters usually include communications problems for which GETS becomes very important.[1-3]

The surge in call attempts during an emergency or disaster often exceeds the engineered limits of the network and creates a condition known as ìoverload.î Several types of overload can result from which GETS users can expect complete or nearly complete relief: [4-6]

- A **general network overload** caused by changes in traffic pattern or increased traffic load
- A **focused overload** generally directed toward a particular location that may result from media stimulation or events that cause mass calling to government or public service agencies, weather bureaus, or public utilities
- A **switching system overload** caused by traffic exceeding the systemís engineered capacity
- A **trunk group overload** during a general or focused overload or during atypical busy hours

Other overload causes not highlighted above include facility outages, inadequate trunk provisioning, and routing errors.

The PSN is engineered to provide a high quality of service (0.98 likelihood of call completion) during the Average Busy Season Busy Hour (ABSBH). In network stress arising from the emergency conditions considered by GETS, the stress may be severe; e.g., overload may be as high as eight times the number of calls experienced in the ABSBH. For comparison, the San Francisco earthquake is reported to have generated an eight times overload at a regional level. As another point of comparison, the Oklahoma City bombing is reported to have generated a four times overload condition. Annually, on Mothersí Day, calling generates an overall network overload of 1.2 to 1.3 times normal ABSBH traffic. At a level of eight times overload, analysis shows that the likelihood of ìplain old telephone serviceî (POTS) call completion decreases to less than 0.15.

As network congestion begins to develop, network management controls (NMCs) are put into place to protect the telephone system from severe overload. This is accomplished by controlling the ratio of calls completed to calls attempted. As a result of network management controls, traffic is systematically rerouted or blocked, and users of the network begin to encounter busy signals. It was recognized that, despite the immense size and speed of the PSN, congestion would occur that would result in telephone calls critical to emergency control and restoration being blocked. As a result, POTS is inadequate to reliably support critical NS/EP requirements.

The potential effect of call volume overload on the Signaling System Number 7 (SS7) network was also examined. The SS7 network normally only generates signaling messages to coordinate call setup for calls that have been allocated a trunk. Since the most a trunk group can experience in terms of overload (i.e., the most trunk allocations and setups it can process) is about 25 percent, this was the maximum anticipated overload for the SS7 network. The SS7 network has been engineered to be very robust, with link sizes that easily handle a 25 percent overload. However, the SS7 network is experiencing rapid growth in traffic for other than call setup messages, e.g., 800/888 number service and Advanced Intelligent Network (AIN) service and, soon, Local Number Portability (LNP) service. This means the SS7 network may become more sensitive to overload situations and more vulnerable to congestion due to large overload excursions. Planned GETS features to address these concerns include an ANSI signaling standard provision for setting the priority of HPC call setup messages at level ìoneî compared to the lower priority of ìzeroî for POTS calls.

GETS Operation and Features

Access to GETS is quick and simple. GETS is accessed through a universal access number using common telephone equipment such as a standard desk sets, secure telephones (e.g., STU-III), facsimiles, modems, and cellular phones. It can also be accessed from telephones on the Federal Telecommunications System 2000 (FTS2000), the Diplomatic Telecommunications Service (DTS), and the Defense Switched Network (DSN). Such direct access is a useful alternative in avoiding congestion or outages in the local carrier networks.

A tone prompt directs the entry of a user-unique personal identification number (PIN) and the destination telephone number. GETS has been designed to ensure that only authorized users access the service through the distribution, use, and control of PINs. Should the access control system fail, GETS calls will still be completed. PINs can be deactivated for fraud or abuse.

GETS is maintained in a constant state of readiness to maximize use of all available telephone resources should outages occur. GETS uses three types of networks:

- The **long-distance networks** provided by the three largest interexchange carriers (IECs)óAT&T, MCI, and Sprintóincluding their international services.
- The **local networks** provided by local exchange carriers (LECs) such as the Bell Operating Companies and Independent Telephone Companies, cellular carriers, and personal communications services (PCS) providers.
- **Government-leased networks** such as the FTS2000, DSN, and DTS.

Once a caller has been authenticated as a valid user, the call is identified as an NS/EP call and receives preferential handling by network features associated with enhanced routing and priority treatment. Among GETS features are the following:

- **Calling Party Number (CPN).** The CPN capability offers GETS call identification through the assignment of a GETS-unique value in the CPN parameter of the SS7 Initial Address Message (IAM). CPN is a parameter in the IAM that identifies the directory number assigned to an originating calling line. The CPN can be used by any network element to trigger call treatment features (e.g., Custom Local Area Signaling Service [CLASS] and Call Redirection features). The GETS CPN replaces the actual CPN with the GETS access number.
- **Alternate Carrier Routing (ACR) and Enhanced ACR**. Alternate carrier routing provides alternate routing from the LEC end office (EO) to the IECs. Upon receiving a GETS call, the LEC EO will offer the call to the Presubscribed Inter-Exchange Carrier (PIC) for that access line, if the PIC is AT&T, MCI or Sprint. If the access line has a PIC other than AT&T, MCI or Sprint, or if the call cannot be connected to the PIC due to congestion or damage, the GETS call will be offered to an alternate IEC, and, if necessary, to a second alternate IEC. Figure 1 shows ACR for the case where an end office (EO) provides both direct trunking and indirect trunking through an access tandem (AT) to all three GETS IECs. GETS calls will be offered via direct trunk in predetermined succession to the three IECs given that the EO to AT trunk remains busy. If control for the call is passed from the EO to the AT, the call will be attempted on the single destination IEC. Should all routes be busy from the AT to this IEC, the call will receive final call treatment, i.e., call control will not be returned to the EO for continuation of EO call routing.

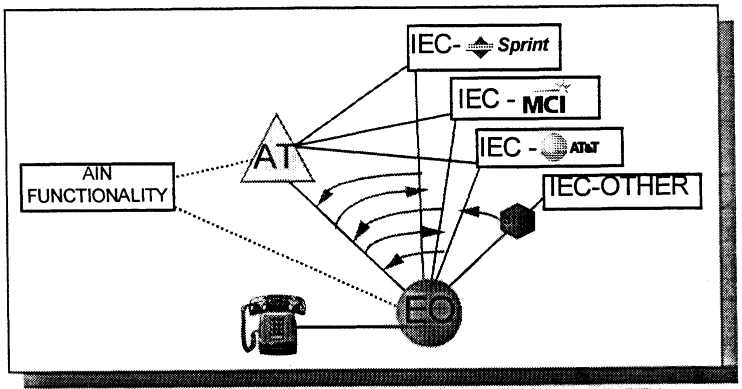

Figure 1. Alternate Carrier Routing (ACR)

The Enhanced ACR feature provides the same basic service as ACR but also supports ACR upon detection of a busy access route from the LEC AT to an IEC. Thus, a GETS call will be routed to an alternate (or second alternate) carrier via direct routes from the originating EO or to alternate indirect routes through the AT. The set of conditions for terminating the Enhanced ACR process include receipt of an answer message or called party busy message by the originating switch or receipt of an address complete message from a downstream switch.

- High Probability of Completion (HPC). The ANSI SS7 protocol standard T1.631-1993, High Probability of Completion (HPC) Network Capability, defines a unique Calling Party Category (CPC) for NS/EP calls. This CPC, referred to as the NS/EP code point, has the value of 11100010 and is a mandatory parameter of the SS7 IAM. When a GETS call arrives at an originating LEC switch, the switch will set the outgoing SS7 IAM CPC to the NS/EP value of 11100010. If the SS7 IAM CPC is set to the NS/EP code point upon arrival in the LEC, the value is passed through the LEC. The HPC network capability standard also assigns NS/EP call packets a signaling message priority of level 1 (with 0 the lowest priority and 3 the highest). The purpose of the SS7 HPC Network Capability standard is identification of a GETS call for priority treatment by signaling and switching elements throughout the PSN.

  Although the HPC capability provides an important benefit for the signaling of GETS call setup, it does not influence priority in Transaction Capabilities Applications Part (TCAP) signaling. GETS uses TCAP signaling to invoke SCP-based AIN service logic for ACR and Enhanced ACR. Although TCAP messages have the same four-level priority structure as messages for call signaling across the SS7 network, all TCAP messages today are signaled at level 0. The HPC standard does not address setting the priority for GETS TCAP messages or how to signal any priority within the message for AIN service logic processing. In the future the GETS program may pursue a standards initiative to ensure GETS TCAP messages are given the same type of preferential treatment as given GETS call setup messages.

- **Exemption From Network Management Controls (NMCs).** Network Management Controls are used to maximize call completion by preventing or relieving congestion in the network during times when the traffic load exceeds the designed capacity of the network. The controls may be manually invoked by network managers or automated, depending on conditions. The exemption from NMCs feature prevents restrictive NMCs applied by carriers in conditions of severe PSN stress from being invoked against GETS calls at an originating EO, AT, or terminating AT, IEC network switch, or international gateway switch.

- **Trunk Queuing.** The trunk queuing feature allows a GETS call to queue for trunks in the event all circuits are busy. The call is placed in a first come, first served queue (allowing multiple GETS calls to wait for a channel on a trunk route). As channels become idle, the GETS calls are routed. If no channels become idle after a set amount of time, the call may be terminated or other GETS features may be invoked. Trunk queuing is to be provided in the originating EO (on the three direct IEC routes and the EO to AT route), in the originating AT (on the three AT to IEC routes), in the GETS IECs and in the terminating AT (AT to EO route).

- **Default Routing**. Default routing allows a GETS call to proceed when the Service Switching Point (SSP) is prevented from receiving a response from the GETS service logic. Default routing provides a form of "fail-open" operation, in which a GETS call is routed to a designated trunk group if call processing instructions are not received from network elements containing GETS service logic within a specified period of time.

GETS improvements are planned for installation in all Local Access Transport Areas (LATAs), but not all switches. Enhanced GETS features are only planned for implementation in the Lucent 5ESS, Nortel DMS-100 family, and AG Communications Systems GTD5 switches. These switch families accounted for approximately 68 percent of the PSN access lines at the end of 1995 and are projected to account for 80 percent of the access lines by year-end 2001 based on technology and market share trends. Siemens has indicated that efforts are underway to address GETS features in their EWSD family of switches but no plans are in place to provision GETS features in EWSD switches at present. Where proposed, the Lucent 1AESS, a large analog EO switch will be provisioned with CPN and ACR features.

GETS Performance During Emergencies

Performance modeling conducted by the GETS IC indicates that the planned GETS features, when fully implemented in EO switches, associated ATs and the GETS IECs will provide a high likelihood of call completion, even during severe network stress. The results of one study, examining the relative improvement of fully-implemented GETS feature performance compared to POTS and GETS with only selected LEC improvements is presented in Table 1 for an eight times overload condition and with elements of PSN damage. Since some switches are not being provisioned with GETS features, the results are presented as performance composites, weighted by switch coverage demographics.

Table 1. GETS Performance Study Results

	CALL COMPLETION LIKELIHOOD	
	Congestion Only No Damage	AT&T Outage Plus Congestion
Overload Level	8	8
Call Out From Zone		
POTS	0.13	0.04
GETS w/o LEC Features	0.62	0.04
GETS w/ ACR	0.83	0.11
GETS w/ Enhanced LEC	0.90	0.71
Added Time Delay (s)	0.60	1.00
Call Into Zone		
POTS	0.13	0.04
GETS w/o LEC Features	0.71	0.14
GETS w/ ACR	0.71	0.14
GETS w/ Enhanced LEC	0.96	0.66
Added Time Delay (s)	2.30	5.80
Call Between Zones		
POTS	0.02	0.00
GETS w/o LEC Features	0.44	0.02
GETS w/ ACR	0.59	0.04
GETS w/ Enhanced LEC	0.86	0.59
Added Time Delay (s)	2.80	6.80

The results of this study indicate a composite likelihood of GETS call completion during periods of high overload of 0.90 for calls out-from a stress zone, 0.96 for calls into a stress zone, and 0.86 for calls between stress zones. The POTS likelihood of completion, for the same conditions, is less than 0.15. In all cases, the delay added to call setup by the enhanced features averages less than three seconds.

When the stress of congestion is compounded with a major equipment outage, the planned GETS improvements continue to provide good performance. In particular, with an AT&T outage (the highest percentage traffic IEC), GETS performance gives composite results of 0.71 for calls out-from a stress zone, 0.66 for calls into a stress zone, and 0.59 for calls between stress zones. This compares to less than 0.05 for POTS calls in all cases. The average added call setup delay is less than two seconds for calls out-from a stress zone, and less than six seconds for calls into a stress zone.

GETS Successes

GETS has already demonstrated its considerable capability to complete calls for NS/EP users when their POTS calls are blocked. Among the recent emergencies supported by GETS are the following:

Central Florida Tornadoes (February 1998)
Northeast Ice Storms (January 1998)
Super Typhoon Paka, Guam (December 1997)
Typhoon Keith, Saipan (November 1997)
Korean Airline Crash, Guam (August 1997)
Reno, Nevada Floods (January 1997)
Hurricane Fran, North Carolina (September 1996)
Hurricane Bertha, St. Croix (July 1996)
Alaskan Wildfires (June 1996)
Oregon Floods (February/March 1996)
Hurricane Opal, Florida (October 1995)
Oklahoma City Bombing (May 1995)
Kobe, Japan Earthquake (January 1995)

Future Challenges

Many of the challenges still faced by GETS involve interconnection and interoperation between networks, such as ensuring that GETS call identification is available end-to-end and understanding the relative benefit of GETS enhancements that reach across network interfaces. In addition, GETS must safely navigate the new services rich, but competition-intense telecommunications environment spawned by the Telecommunications Act of 1996. Selecting the most appropriate solution to these challenges will require a thorough understanding of the architecture over which GETS is implemented, new technologies, services and features and particularly the interfaces among networks.

Summary

GETS is a valuable telecommunications capability for authorized government NS/EP users enabling a high rate of successful call completion during network congestion or equipment outage arising from natural or manmade disasters. The service is integral to the PSN and thus benefits from its ubiquity, robustness, and flexibility as well as from technological advances within the industry. Analytical studies indicate a high likelihood of call completion for both high congestion and equipment outage (with accompanying high congestion conditions) within the PSN when all switches in the call path are provisioned with planned GETS improvements. This compares to a very low likelihood of POTS call completion for the same conditions. GETS is an existing, yet maturing, capability that, like other services, must be continually evaluated within the context of an ever-changing PSN environment to bring a quality service to its users.

References

1 FEMA News Release No. 94-228, 30 December 1994

2 FEMA Disaster Activity Fact Sheet, January 1 to June 5, 1995, Document Number 93009

3 FEMA Disaster Activity Fact Sheet, January 1 to September 30, 1996, Document Number 93010

4 ANSI T1.202-1988, Internetwork Operations ñ Guidelines for Network Management of the Public Switched Networks Under Disaster Conditions

5 ITU-T Rec. 410, International Network Management ñ General Information

6 Bellcore, "BOC Notes on the LEC Networks ñ 1994," SR-TSV-002275, Issue 2, April 1994

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Telecommunications Emergency Operations in Pacific Bell

by

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Abstract

The security and defense of the United States, as well as the health and welfare of the populace, could depend in part on the continued functionality of the national telecommunications network prior to, during, and after an emergency. This network is a critical resource to disaster response capability, and its value will be maintained only if operational continuity is assured through development and implementation of effective disaster response programs. Since emergencies strike with little or no warning, inadequate preparation could result in grave consequences to citizens, communities, and the nation.

Pacific Bell has established a well-respected emergency preparedness program able to cope with disaster events. This benchmark program has proven to be effective in events such as the Loma Prieta and Northridge earthquakes, rural and urban wild fires, floods, and civil unrest. To ensure a constant state of emergency readiness is maintained, large scale disaster exercises are regularly scheduled to evaluate overall program readiness.

Pacific Bell regards Emergency Preparedness as a fundamental responsibility necessary to preserve the California State Telecommunication Infrastructure and a strategic market differentiator. Our policy is to achieve the necessary preparedness and disaster response capability which has been guided by a well thought out plan enabling trained employees to effectively execute emergency roles.

Emergency Preparedness efforts are aimed at providing the organizational structure, resources, and disaster response training necessary for consolidated and effective Company-wide response. The plan objectives are:

- Protect the life, safety, and health of employees and customers
- Protect Company property and assets
- Provide for large-scale Network restoration and resumption of normal business operations as quickly as possible.

Pacific Bell has two critically important assets:

- the Employees, and
- the Network.

Pacific Bell has always emphasized restoration capability, processes, and structure. We have demonstrated, under the worst of conditions, our ability to restore the Network in the shortest possible time. The concept of the Emergency Preparedness and Response Plan is to emphasize the following major areas:

- A readiness capability of a core group of employees sustained over time through an ongoing certification process that includes participation in disaster recovery exercises and special preparedness/recovery training, instead of relying on a large amounts of documentation that soon become outdated.
- A tiered or stratified structure of emergency management personnel (Emergency Management Organization) merging regular day-to-day repair operations personnel with a multi-discipline functional team of managers supported by an officer team. The EMO is considered a part of our long-term marketing strategy to provide better customer service.
- Pre-disaster Planning (Pre-plans) containing detailed disaster assignment checklists. Pre-plans are used so predetermined responses can be routinely implemented immediately following a disaster.
- Emergency alternate (i.e., back-up) communications capability for the key personnel within the emergency management structure.
- Preparedness, Response, and Recovery programs for the protection of employees and assets, including the Public Switch Network, Facilities, Operational Support Systems, Emergency Restoration Equipment, and Vital Business/ Operations Records.

Emergency Management Organization

The Emergency Management Organization (EMO) is an organization that exists to provide policy, direction, coordination, and overall management of emergency operations within Pacific Bell. It is comprised of groups of key individuals from various levels of the Company, and acts in a consolidated and coordinated manner to prepare for, respond to, and recover from a disaster. The responsibility of the EMO is to:

1. Develop and maintain Emergency Preparedness and Response Plans.
2. Establish and maintain liaison with federal, state, and local government agencies.
3. Conduct, support, and evaluate disaster response drills and exercises.
4. Activate the EMO as required.
5. Implement Pre-plans and begin restoration activities.
6. Provide continuing support and resources until service is restored to normal.
7. Collect and evaluate building site and Network damage information.
8. Evaluate Pre-plan effectiveness and coordinate appropriate upgrades.
9. Recommend/ implement mitigation projects.

Emergency Preparedness and Response Program Elements

- Hazard Analysis and Risk Reduction

  Through ongoing hazard and vulnerability analyses, mitigation programs are implemented to ensure the safety of employees and the integrity of the Network.

- Continuity of Operations Plan (COOP)

  The COOP establishes the emergency structure, standards, and procedures for the performance of those functions necessary to reconstitute the network and restore customer service following a disaster.

- Continuity of Management Plan (COMP)

  Emergency response organizational plans are established to enable officers and key personnel to perform the functions of their office in support of disaster restoration efforts.

- Alternate Sites

  In the event that primary emergency center sites are damaged as the result of a disaster, alternate sites for emergency operations have been identified.

- Employee Preparedness

  Employees are trained in personal safety techniques, according to guidelines established for specific work groups and environments. Through the Site Manager/ Building Warden Program, all employees are trained in site-specific emergency procedures, and selected employees are trained to perform specific emergency functions (e.g., first aid) at the time of a disaster.

  - An Earthquake Survival Guide, which outlines preparedness measures to be taken in the home and at the workplace, is available to all employees.
  - Emergency public information in the form of a Survival Guide, which can be used for employee awareness, is included in Pacific Bell telephone directories.
  - An Employee Home Disaster Plan is available to all employees. This plan primarily focuses on preparing the family for a major disaster and assisting in the post disaster recovery process.
  - The Employee Emergency Communication Center may be activated in time of a disaster to serve a place for employees and their immediate families to leave messages for each other. The EOC leadership team is responsible for the activating this communications center.

- Emergency Supplies and Equipment

  Employee reporting locations are provided with first aid supplies, fire extinguishers, etc. Reporting locations with six or more employees also have sufficient emergency supplies to sustain employees for up to three days. This includes food, emergency lighting, water, etc. In some cases, supplies are stocked in a remote location.

- Restoration Equipment

  Mobile emergency power generators, microwave transmitters/receivers, cable, fiber optics equipment, and fully equipped restoration trailers are strategically located throughout the State. Electronic plug-in equipment and other essential equipment is also maintained.

- Training Exercises

  Disaster training exercises are conducted by each EOC, Control Center, and Computer Center on a regular basis. These exercises are designed for training purposes and to maintain disaster response capability. In addition, Site Managers/Building Wardens conduct employee fire and earthquake take-cover drills on a semi annual basis.

- Public Awareness

  Emergency public information in the form of a Survival Guide, which can be used for employee awareness, is included in telephone directories. Films depicting the work done by Pacific Bell and public safety agencies to provide better communications and a safer environment are available. During a disaster, the External Affairs Department provides an interface between the Company, the public, and the news media and will provide the public and employees with information concerning service interruptions and anticipated restoration timelines through electronic and print media.

- California Utilities Emergency Plan

  The California Utility Emergency Plan, an annex to the State of California's Emergency Plan, addresses the California gas, electric, water, and telecommunication utilities' response to extraordinary emergency situations associated with natural disasters, technological incidents, and war emergency operations.

Concept Of Operations

- General

  Emergencies and service interruptions that can be restored with resources under the jurisdiction of Control Centers are managed locally. More large scale incidents are managed by activation of those levels of the EMO deemed necessary .

- Activation

  Any manager within the EMO has the authority to activate the EOC. EMO members are the only levels authorized to designate an event a disaster and to activate all levels of the EMO.

- Notification and Reporting Procedures

  When an EOC is activated, all reports will be made to the EOC. The EOC Team will keep the ECC informed of events and progress.

- Pre-plans

  Emergency operations are governed by established Pre-plans which are specific to the serving area, technology, and Network service. Pre-plans have specific designs to protect employees and Company assets, and for restoring the Network and customer service.

- Coordination with Local and State Government

  Pacific Bell is a member of the California Utilities Emergency Association (CUEA) and the Telecommunications Industry Advisory Committee which have been established to address issues of mutual interest and concern regarding emergency preparedness and response. Pacific Bell representatives may also act as government liaisons at the State Coordination Center and at State OES Regional EOCs during declared disasters.

- Mutual Aid

  Pacific Bell currently has Mutual Aid agreements with Regional Bell Operating Companies and other California Telephone Companies. Requests by Pacific Bell for resources or equipment are made through the activated Emergency Operating Centers or the Emergency Control Center as requested by the EOC. Requests coming into Pacific Bell for assistance are made through the Company's Emergency Preparedness Staff.

Levels of Disaster Occurrences

Governmental agencies divide disasters into three levels which are determined by the type and magnitude of the event.

- Level I.

  The government definition of a Level I Disaster applies to situations which are deemed abnormal conditions by Pacific Bell. The EOC is not activated.

- Level II.

  A moderate to severe incident requiring coordination of several disciplines. The Area EOC may be activated, or EOC Team members may function on a remote basis from the respective Control Centers. In this case, activation may be on a full or limited basis.

- Level III.

  A major incident that requires the deployment of extensive resources from throughout the state and possibly outside the state. This level of disaster is very likely to be caused by a major earthquake which would severely impact all Pacific Bell departments. The EOC in the disaster area would be activated and the other EOC would activate in support of the primary EOC.

Disaster Types

California is at risk from a wide variety of disasters, ranging from fires, floods, and chemical spills to devastating earthquakes. Since a major earthquake has the potential for causing widespread destruction, injuries, and death, it is considered the "worst case scenario" and forms the basis for public and private sector disaster preparedness and response efforts.

- Major Earthquake

  The California Division of Mines and Geology has developed scenarios which outline anticipated damage following a major earthquake, which include damage to telecommunications, transportation, utilities (Power/Natural Gas/Petroleum).

- Fires

  California is at risk from wild fires as well as from urban fires (including high-rise buildings). Such incidents may require the evacuation of buildings or areas. Major communications centers could be affected, damaging electronic equipment.

- Flood/Dam Failure

  Winter storms have demonstrated that California is prone to flooding. Floods may be slow-rising or they may be sudden. In a dam failure, flash flooding would occur requiring immediate evacuation of entire areas. Power may be disconnected in flooded areas to protect electronic equipment.

- Hazardous Material Spill.

  Hazardous material spills can occur anywhere, but they most frequently occur along transport facilities. The release of hazardous materials can cause fatalities and injuries and/or damage to network equipment. In addition to the measures that must be taken to protect employees, there are substantial service risks associated with hazardous materials coming in contact with equipment. Corrosion, electrical shorts, and extensive cleanup work could delay the restoration of communications facilities.

- Extended Power Outage

  Although not necessarily life or property threatening, an extended power outage could have a significant impact on all Company operations.

- Sabotage/Terrorism.

  Industrial sabotage/ Terrorism is a threat which confronts every major business and can be manifested in a variety of ways, including bomb threats, direct damage to equipment or electronic intrusion.

- Nuclear Defense Emergency.

  Due to the serious consequences of a nuclear attack or accident, operations preceding and during such an event will be directed by the federal government. Essential actions will include certain increased readiness measures.

Standardized Emergency Management System in California[1]

by

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Introduction

The State of California, with more than 35 million residents, has experienced eight major disasters within the past seven years that have affected many of the highly urbanized and technology dependent areas of the S. These disasters have included earthquakes (Loma Prieta 1989, Landers-Big Bear 1992, Humboldt 1992, Northridge 1994); fire storms (Oakland 1991, Southern California 1993); civil unrest (Los Angeles 1992); and floods (1995, 1997 and 1998). The California Governor's Office of Emergency Services (OES) oversees a comprehensive series of disaster preparedness and response programs designed to meet the threats posed by both natural and technological hazards. Every disaster is preceded by opportunities for mitigation and preparedness, and is followed by relief and recovery efforts. OES programs address each phase: **mitigation** of existing hazards and reduction of risk; **preparedness** for disaster response; **response** to events; and the support of **relief** and **recovery** efforts, as illustrated in Figure 1. These programs are defined by the California Emergency Services Act[2], the State Constitution and traditions within the United States that emphasize "local home rule," governance at the lowest level of government.

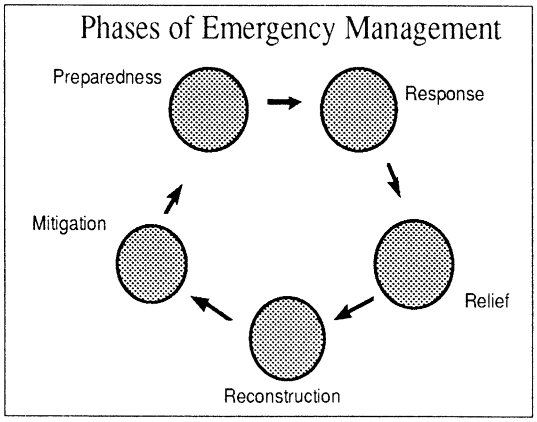

Figure 1 Phases of emergency management cycle.

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[1] Paper submitted to the World Urban Earthquake Conference in Fukui, Japan, June 1998

[2] California Emergency Services Act, Chapter 7, Division 1, Title 2 of the Government Code, as amended

Context for Emergency Management in California

California is composed of 58 semi-autonomous counties that serve as agents of the state government, and more than 450 autonomous municipalities. Under the State Constitution, the power and responsibility to regulate land use and development and provide for public safety belongs to these local governments. Often referred to as "Police Powers," these delegated responsibilities are defined in the California Emergency Services Act (ESA) of the Government Code. In addition, the ESA provides for state and regional roles for the Governor's Office of Emergency Services in promoting, assisting and supporting local mitigation, preparedness and response activities to ensure capability and consistency. Guided by the concept of "local home rule," the state's role is limited to providing guidance and assistance to local governments before disasters, and to providing resources to local governments during and after disasters. When state resources are provided to a local government, including the provision of state agency personnel and National Guard troops and equipment, those resources serve under the direction of the local government agency requesting assistance. This provision of local control also governs the management of federal resources requested by the state and provided to assist a local jurisdiction. Federal agency personnel, whether from the U. S. Geological Survey, Forest Service, Bureaus of Reclamation and Land Management or the military, serve at the direction and pleasure of the local government.

A critical element of "local home rule" is that, regardless of the magnitude of the disaster, the local government officials are in-charge of the response. (A exception to this concept is for a terrorist act threatening the local population with weapons of mass destruction [nuclear, chemical or biological weapons] wherein agencies of the federal government [Department of Defense, Public Health Service, Federal Bureau of Investigation] are the lead agencies for this response.)

The hierarchy of government response delegates responsibility to the local level of government, with regional, state and federal agencies providing support and resources upon request, as illustrated in Figure 2. The benefit of this approach is that decision making is made by responsible local officials who are familiar with the problems being encountered, rather than at a level of government or location remote and removed from the scene. This approach also supports local initiative, rapid and responsive decision making, and accountability of local officials to their constituents.

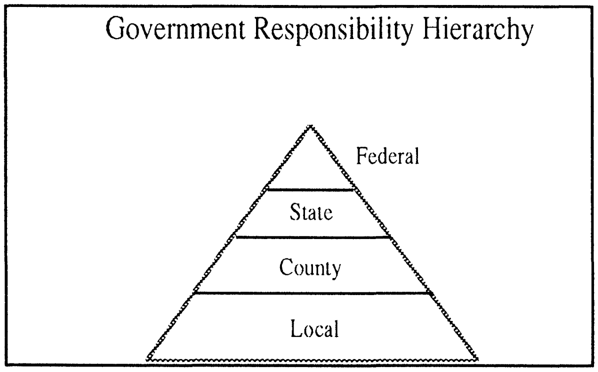

Figure 2 Hierarchy of government responsibility.

The long standing tradition of "mutual aid"[3] between and among local governments supports local governments and locally focused response is. This concept of "neighbor helping neighbor" is codified in the Emergency Services Act and stipulates that assistance provided is offered without the expectation of reimbursement. The managing of the mutual aid system is the responsibility of Operational Area (county) or regional officials to serve as brokers and coordinators of local resources. When local governments request assistance from adjacent jurisdictions through the mutual aid system, the assistance (personnel and/or equipment) provided is under the direction of the requesting local government.

Underlying assumptions of the mutual aid system include the expectation that most local governments could not afford to be totally self sufficient, that there are economies from sharing resources; and that eventually, every jurisdiction will have the opportunity to be both a donor and recipient of mutual aid resources. The Master Mutual Aid Agreement[4] provides the authority to implement resource specific mutual aid agreements among local governments. Such agreements now provide for mutual aid by fire, law enforcement, public works and emergency management personnel.

The Role of the Federal Government in Disasters

With the exceptions noted above, the role of the federal government during disasters is limited -- consistent with tradition and the Constitution of the United States that declares broad powers and responsibilities are retained by the states and the powers of the federal government are therefore limited[5]. Even when federal resources are provided to local governments, the local government remains in control of emergency response activities..

The Federal Emergency Management Agency (FEMA) provides pre-disaster training to local government emergency managers, and provides limited assistance is provided to states and local governments to support general emergency management (Emergency Management Assistance Program). FEMA's Emergency Management Institute (EMI) provides a range of training and development options for state and local government officials. While federal assistance before disasters is limited, the federal role in post disaster relief and recovery is significant. When a local disaster exceeds the response or recovery resources of a state, the declaration of a Federal Disaster by the President provides extensive federal financial assistance to both affected governments and individual disaster victims. Under provisions of the Stafford Act[6], assistance is provided to cover the costs of response, reconstruction and mitigation of hazards. Emergency response hierarchy is illustrated in Figure 3

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[3] Article 11, Section 8615 et al., California Emergency Services Act

[4] Article 2, Section 8561; Article 11, Section 8615 through 8619

[5] The 10th Amendment to the U.S. Constitution reserves to the states those powers not specifically delegated to the federal government

[6] See: Stafford Act, Public Law 93-288, as amended

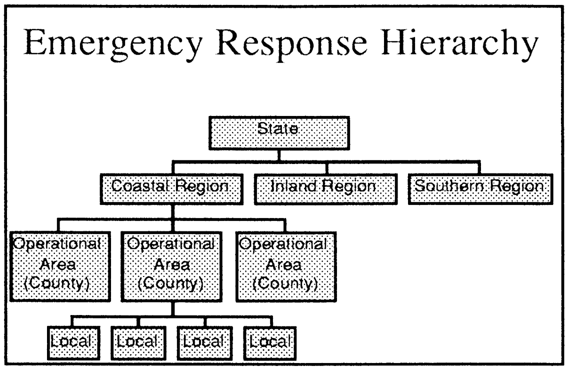

Figure 3 Emergency response hierarchy within a state.

Dilemmas for Local Government

Local governments face difficult decisions in preparing for possible disasters. Most natural and technological threats are uncertain and of low probability. Yet, local governments must prepare for their consequences. Infrequent disasters are not generally the motivator of a constituency to support funding from a limited tax base, particularly when there are well-organized constituencies competing for revenue to support a host of public services from schools to health services. Secondly, effective emergency management requires a knowledge and experience that comes from disaster crisis decision making. Few jurisdictions have the frequency of disasters to train and maintain a knowledgeable emergency management cadre. In addition, as revenues decline for local government programs, many of the most experienced emergency managers have retired or left government service.

It is often said in sports that, "You play the way you practice." Training and exercises while helpful, are seldom a substitute for actual experience. It is difficult to simulate the stress, fatigue and complexity of actual disaster response in an exercise. Emergency managers must play well above the level of their practice! Unfortunately, many local governments lack adequately staff and/or staff trained to effectively manage a disaster without assistance.

Historically, political diversity and individuality provided choice and adaptability to local need at the local government level. Unfortunately, numerous variations in emergency management organization created a multitude of variations in systems, organization, terminology and procedure that made sharing resources and personnel dysfunctional. In 1991, a firestorm struck the city of Oakland in the San Francisco Bay Region. The intense hot wind driven fire consumed 3,500 homes and claimed 25 lives within 4 hours, resulting in the greatest urban conflagration since the 1906 San Francisco Earthquake and Fire. As the fire spread toward downtown Oakland, thousands of firefighters and their equipment converged on the fire scene. Without a common organizational structure, consistent terminology for equipment and tactics, compatible radio equipment and frequencies, or standardized hose fittings, arriving resources could not be integrated into an organized fire fighting force. Only a reduction in winds and afternoon cooling temperatures prevented a greater disaster.

In the aftermath of the Oakland Fire disaster, state and local government officials in California joined together to create a more effective emergency management structure. They recognized the need for a uniform, standardized system that would provide the compatibility necessary for efficient use of limited local resources, while facilitating the integrating of state resources when and where necessary.

Development of the Standardized Emergency Management System (SEMS)

In the aftermath of the Oakland Hills Fire, the State of California mandated that all local and state agencies involved with disaster response utilize the Standardized Emergency Management System (SEMS). SEMS was modeled after the Incident Command System (ICS), a standardized system of managing fires in southern California.[7] ICS and SEMS were modeled on the following simple concepts:

- A simple and clear standard organizational structure that is modular and ca expand or contracted as necessary, and that facilitates interchangeability of personnel
- Provides for multi-agency and hierarchical coordination
- Management by objectives -- clearly defined priorities and objectives to be achieved during a specific period of time
- Clear management structure and well defined command authority
- Limited span of control -- reporting and management limited to 5 to 7 individuals or units
- Accountability and financial control of operations

ICS had been tested extensively as a field management concept in urban and wild land fires in southern California for more than a decade. Its attributes were adopted for field use in emergency management and incorporated as core concepts for overall emergency management. In addition, the mutual aid system in the state that supported fire and law enforcement operations was adopted as an element of SEMS.

The Operational Area concept, intended for use during war emergencies, was adapted for SEMS in order to create an effective statewide organization and reasonable span of control hierarchy. Under the OpArea concept, all jurisdictions within a county, would coordinate their operations through the county and report to the state through the county. The county would become an operational unit or Operational Area within the state, reducing the number of governmental units reporting to the state from several thousand (58 counties, 500+ cities, 5,000+ special districts) to 58 Operational Areas. At the state level, California was divided into three administrative units, conceived of as being able to operate independently during either regional or statewide disasters. These are illustrated in Figure 4. This decentralization and delegation of responsibility to the Inland, Coastal and

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[7] California Emergency Services Act, Article 9.5, Section 8607 et al. as codified in California Code of Regulations, Title 19, Division 2, Sections 2400 through 2450, as amended

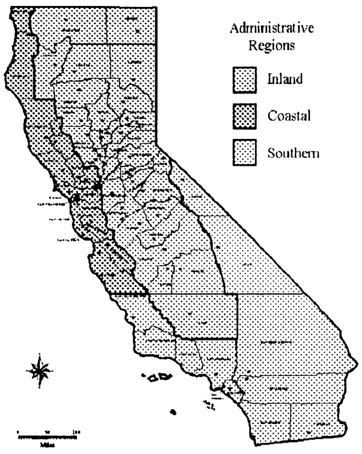

Figure 4 Administrative regions of California

Southern Regions were designed to provide more rapid and effective response to major disasters by empowering OES Regions to make decisions and commit state resources, and once again, to provide a manageable span of control for state officials. Previously, all decisions were made at a single State Operations Center in Sacramento that frequently was overwhelmed by large, multi-jurisdiction disaster events.

SEMS Management Concepts

SEMS provides a standardized organizational structure at all levels of government. At the local (municipal) level, the organizational structure is identical to the organizational structure being utilized at regional or state agencies. The consistency of organizational concept ensures compatibility of staff, mutual aid resources, and a uniformity of local and state organizations that enables both small rural counties and large urban counties to interchange staff without a loss of efficiency or redefinition of roles and responsibilities.

SEMS is organized into five basic functions: Management, Operations, Plans, Logistics and Finance/Administration. These are illustrated in Figure 5.

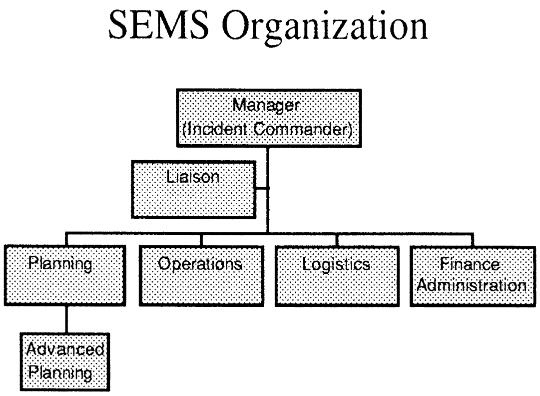

Figure 5 SEMS basic functions.

- **Management** is the single person or team that is responsible for making decisions, setting priorities and ensuring the objectives are met.

- **Liaison** provides connections to federal or state agencies that are participating in the response but do not have direct responsibility for response actions

- **The Planning Section** provides analysis of the disaster, collects information and intelligence from local governments (OpAreas), develops Situation Reports and documentation, and develops Action Plans for **Management**. An Action Plan is a set of objectives and priorities that provide the basis for disaster operations. **Advance Planning Unit** develops long term (days to weeks) assessments of disaster impacts and projected resource requirements.

- **The Operations Section** works to identify required resources and organizes response activities. At the local level, Operations would manage overall field operations. At the Regional (state) level, Operations coordinates state and regional agency response.

- **The Logistics Section** locates and acquires resources needed by the **Operations Section,** the SEMS organization or field operations.

- **The Finance and Administration Section** keeps records of personnel, payroll and costs, and processes purchases.

Communication Infrastructure

A robust communication system is essential for effective emergency management. Communication becomes critical when it is necessary to coordinate multiple agencies, multiple levels of government and span long distances. Linking California's 58 Operational Areas and a multitude of state agencies posed a formidable challenge to California OES. The system would have to be able to withstand natural and technological disasters, provide for multiple routes to avoid single points of failure, be able to provide high speed data and text transfer, and had to be integrated into available information system hardware and software. The Governor's Office of Emergency Services selected Lotus Notes software as the base application for internal management communications and as the platform for development of emergency management applications. The communication infrastructure is illustrated in Figure 6.

The **Response Information Management System (RIMS)** provides a simplified system for reporting disaster situations (Situation Reports), requesting assistance or resources (Mission Requests), tracking resources (Mission Tracking), and for reporting and documenting damage (Initial Damage Estimates). Data and/or requests for resources are entered into form templates on computers at each of the Operational Areas. OpArea data is transferred to one of three OES Administrative Regions where reports are reviewed and aggregated and requests for assistance are routed to responding state agencies. Regional reports are transferred to the State Operations Center and the Governor's Office in

Sacramento. Requests for assistance are monitored from initial request, through coordination of state response, and finally to completion of mission on the RIMS system.

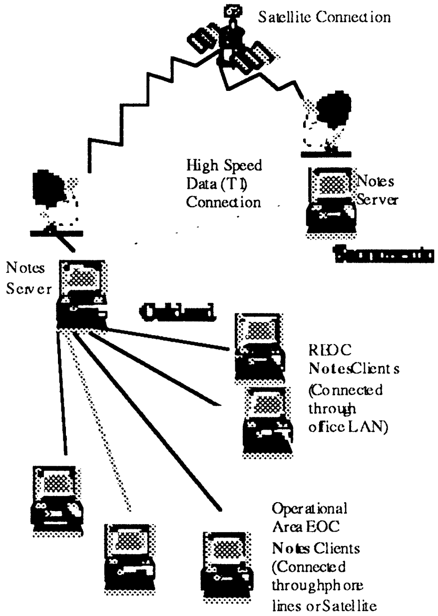

Figure 6 Communications infrastructure.

In order to provide for communications among the various levels of government and within the state level response agencies, RIMS data is normally transferred between OpAreas and OES Regions over either conventional telephone lines or through an Internet Service Provider (ISP). OES links to the internet through a hub in Sacramento. The OES Regional Emergency Operations Centers are normally linked to the Sacramento State Operations Center over a high speed, high capacity T-1 telephone line capable of transmitting data at 1.544 MBPS bytes per second or through an ISP.

To ensure robust and near failsafe communications between OpAreas and Regions, and between Regions and SOC, each of the state's 58 Operational Areas and the three OES Regions are provided with a satellite based telecommunications system (Hughes VSAT) capable of transmitting both data (at 19.2 KBS) and voice. Each Operational Area Satellite Information System (OASIS) installation is supported by an emergency generator, and an uninterruptable power source (UPS) to ensure continued operations and communication should land based telephones or power be interrupted.

Initial Testing and Evaluation of SEMS and RIMS

The winter floods of 1995 and 1997 provided an initial evaluation of SEMS during it development and early fielding. The decentralization of decision making to the OES Regions and the reliance on the Operational Areas as a single point of state contact with local governments greatly enhanced the efficiency of emergency operations. During the 1997 floods, all 58 counties in California were actively involved in disaster operations.

The OES Regions were able to effectively respond to their requests for assistance and to track resources.

The first full test of SEMS and RIMS occurred during the Winter Floods of 1998. During the January storms, 31 counties were devastated by El Nino enhanced rains and resulting flooding and land slides, disrupting transportation and communication. Operations were carried out using SEMS at local and state levels and using the RIMS communication system to request and monitor resources. The initial assessments indicate that the overall concepts of both the Standardized Emergency Management System and the Response Information Management System are sound and in need of only minor improvements in computer and communication technology to provide the capability that was envisioned.

Conclusions

As with any essential communication system, there needs to be redundancy in operating systems, redundant network nodes and multiple paths for linking nodes. The implementation of SEMS and RIMS, utilizing public and dedicated telephone, Internet connectivity, and OASIS satellite links provide necessary multiple routing and system redundancy. Vulnerability of the system now rests at the command center level, with the physical facilities utilized by state and local government agencies for emergency operations and command centers. While most local and state emergency operation centers were constructed to be resistant to nuclear attack during the 1950s, few are able to meet current design standards for essential services facilities and maintain operational capability after a major earthquake. A notable exception in the new county EOC facility built on a base isolation systems in Los Angeles.

Appendix A
Workshop Information

Workshop Program

9:15 Introductions and brief comments by participants if they so desire.
10:00 The issue of determining if seismic performance criteria are satisfied prior to a major disaster.
10:20 CO Facilities - Buildings, building support systems, emergency power, concentration of resources
11:00 Outside Plant - Fibers, remotes and repeaters, route diversity
12:00 Lunch
12:45 Congestion - Measures of performance, essential service lines, Government Emergency Communications Service (GETS), line load control
1:45 Emergency Response - Telco emergency operations
2.30 Break
2.45 User Needs - Emergency government (Office of Emergency Services or civil defense), general public
3:45 Special Topics (We will not discuss national security issues.)
  Impact of deregulation
  Measures of total system capacity
  Pre-event measures of performance
4:45 Meeting summary and final report
5:00 Meeting Adjourned

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*** Submitted paper but could not attend the workshop

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