PUBLIC SAFETY
PSWN PROGRAM
WIRELESS NETWORK

Saving Lives and Property Through Improved Interoperability

Public Safety In-Building/In-Tunnel Ordinances and Their Benefits to Interoperability Report

FINAL

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PREFACE

Effective and interoperable wireless communications are critical to the success of public safety operations. One specific area of wireless communications that has become increasingly important to public safety professionals is providing adequate wireless communications while operating inside buildings and tunnels. To resolve this issue, some governments have codified requirements for improving access to public safety wireless networks. The degree to which ordinances have been adopted and their overall effectiveness as a solution to the problem are not generally understood by the public safety community. In response to the various inquiries from the public safety community and the need for new solutions for improving wireless networking interoperability in all operational environments, including inside buildings and tunnels, the Public Safety Wireless Network (PSWN) Program conducted a study of the issue. This report is the result of that study and provides a variety of findings that can serve as a resource to public safety professionals attempting to resolve in-building communications problems.

This report reviews and analyzes existing and proposed in-building communications ordinances and their effectiveness in promoting improved wireless public safety communications. This report does not address the issue of in-tunnel communications because the PSWN Program research team identified no related ordinances. The report identifies localities with in-building ordinances or codes and examines the similarities and differences in these ordinances, the reasons for their development, and trends in regulating indoor wireless public safety communications.

The establishment of in-building communications ordinances is a recent trend, and all of the regulations studied have been considered or adopted since 1991. These laws were created in response to new requirements of public safety community. This report examines the relevant issues prompting creation of the ordinances and how the relevant laws came into being. The report also investigates sources of political authority for creation of ordinances and rules that can set requirements on construction to guarantee reliable in-building public safety wireless communications. Finally, the report discusses the trends the research team observed—from the creation of the first ordinances to present approaches for passing such regulations. The goal of this report is to fully assess the effectiveness of using ordinances as a means to improve in-building wireless communications for public safety operations.

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SUMMARY REPORT

1. INTRODUCTION

The importance of in-building communications was magnified during the New York City Fire Department (FDNY) response to the World Trade Center terrorist attack. During that and other emergencies in high-rise buildings throughout New York City, New York, firefighters have not had reliable in-building wireless communications. This problem is occurring in many parts of the country and threatens the lives of public safety officials and inhibits their ability to perform their missions. To help resolve this problem, many localities have passed ordinances or other laws that require building owners to provide access to the public safety wireless networks inside their buildings.

The purpose of this report is to review and analyze existing and proposed in-building and in-tunnel communications ordinances, and to analyze their effectiveness in promoting improved wireless public safety communications. The report identifies localities with in-building ordinances and codes and examines the similarities and differences in these ordinances, the reasons for their development, and trends in regulating indoor wireless public safety communications. The development of in-building communications ordinances to improve the quality of public safety wireless coverage by legislating standards for quality and use is still a relatively new and innovative concept, dating back only to 1991. The ordinances and building codes are, in general, designed to allow public safety radio system operation inside buildings and facilities that are open to the public. The responsibility to comply with the ordinances and the costs of ensuring coverage within the building are usually borne by the building permit holder. The goal of this report is to fully assess the effectiveness of using ordinances as a means to improve in-building wireless communications for public safety operations.

This study further examines how relevant laws came into being. It investigates the sources of political authority for creation of ordinances and rules that can set requirements for communications and construction to guarantee and enforce reliable in-building public safety wireless communications. The report also discusses the trends the Public Safety Wireless Network (PSWN) Program research team (research team) observed—from the creation of the first ordinances to present approaches to passing such regulations. As public safety agencies across the country have replaced or upgraded their communications systems, officials have also started to recognize the need for improving in-building coverage due to the detrimental effect poor wireless coverage has on public safety operations. This study reviews common engineering problems and the solutions implemented to address the issues surrounding in-building communications coverage and to successfully resolve these issues. The report examines sources of interference, changes in building composition, and additional factors that in-building communication solutions can overcome to meet the requirements set by the identified ordinances.

1.1 Scope

This report details research performed to identify the body of legislation successfully enacted to ensure access by public safety personnel to their wireless networks while they perform operations inside buildings. Specifically, the report provides findings regarding in-building communication regulations that have become law in seven different jurisdictions. In addition, the report examines four other jurisdictions that are attempting to codify ordinances and recounts the current status of each of those initiatives. Moreover, the report addresses the technical issues surrounding in-building wireless communications, presenting technical solutions that jurisdictions have implemented to resolve these issues. The report also addresses the costs associated with in-building solutions. Finally, the report analyzes the perceptions of public safety professionals and the impact of the ordinances.

1.2 Approach

The research team used a three-phased approach in performing this study: data collection, analysis, and study reporting. This approach is illustrated in Figure 1 and described in the following paragraphs.

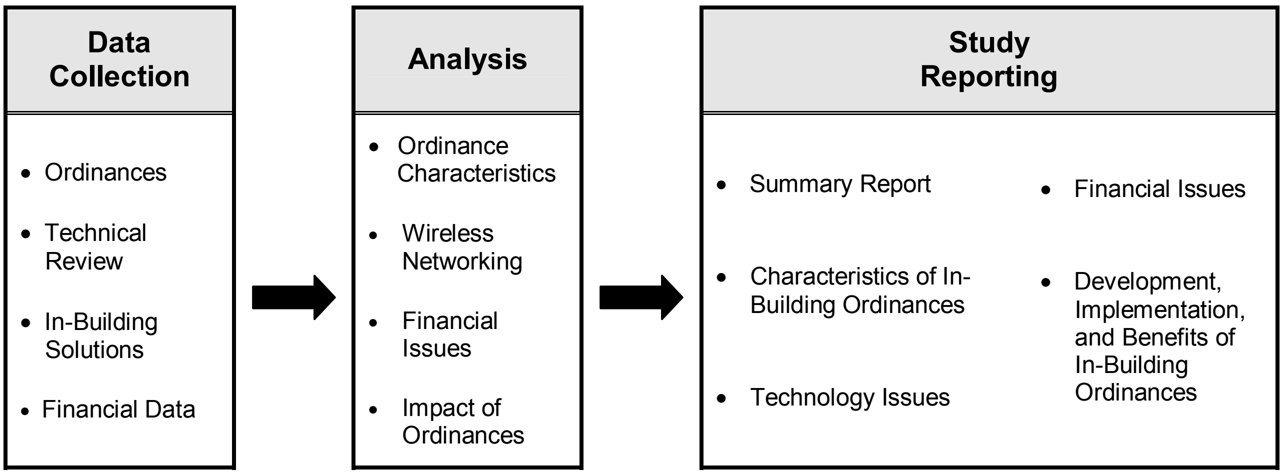

Figure 1
Study Methodology

Data Collection…

During the data collection phase of the project, the research team addressed the following subject areas:

- **Established and Proposed In-Building and In-Tunnel Ordinances**. This data gathering effort had two focuses. First, the team identified seven jurisdictions with codified in-building ordinances and four jurisdictions with proposed ordinances. The research team made extensive use of various electronic research services, including online legal databases and search engines, to gather data regarding local ordinances that govern in-building and in-tunnel communications. The research team also performed additional research by establishing personal contacts with various public safety associations and organizations and through already existing contacts created by PSWN Program outreach efforts. The team also reviewed various text sources, including the National Fire Protection Association, International's *Fire Prevention Code*, *Code for Safety to Life from Fire in Buildings and Structures*, and *National*

Electrical Code. Next, the research team developed a survey tool/questionnaire to gather more detailed information from the jurisdictions identified as having established or proposed ordinances. The team then contacted the jurisdictions and interviewed approximately 30 interested public safety professionals.

- **Technical Issues Related to the In-Building Ordinances**. The research team reviewed an assortment of academic, technical, and periodical materials, along with previous documents developed by the PSWN Program including the PSWN Program's *In-Building/In-Tunnel User Considerations Report*. The team examined a variety of research materials to ensure that the scope of the in-building problem was thoroughly evaluated and explored. The research team conducted interviews with several technical, operational, and industry experts to guarantee that key technical points related to in-building ordinances were identified.

- **In-Building Solutions for Improving Coverage Inside Buildings**. To provide a comprehensive view of the types of equipment and hardware available for resolving in-building wireless problems, the research team conducted extensive online research and interviewed several equipment vendors and professional system installation representatives to gather additional information on products available in the marketplace.

- **Financial Issues Related to In-Building Solutions**. To develop cost estimates for a financial analysis for in-building solutions, the team conducted extensive online research in addition to interviews with prominent vendors whose service offerings focus on in-building communications.

Analysis…

To begin the data analysis phase, the research team assessed the overall findings of each of the previous research efforts, organizing the findings into the following four areas:

- **Characteristics of In-Building Ordinances**. These findings include similarities and differences among the seven jurisdictions with ordinances already in place and the four other jurisdictions with either proposed ordinances or ongoing initiatives for developing in-building regulations. The research team compared and contrasted the ordinances based on the type of systems requiring in-building enhancement, desired signal strength, coverage and reliability, technical solutions outlined in the law, testing procedures, enforcement provisions, and exemptions.

- **Technology Issues**. The findings provide the reader with the necessary technical context to understand the problems associated with wireless coverage inside buildings. This includes an overview of public safety wireless networks and in-depth analysis of in-building coverage, and the technical solutions for improving in-building coverage.

- **Financial Issues**. These findings pertain to the overall costs related to implementing in-building wireless communication systems. The findings also illustrate that the cost of wireless solutions inside buildings is related to the type of building, the timing of the design and installation of the solution, and the severity of the in-building coverage problem.

- **Development, Implementation, and Benefits of In-Building Ordinances**. This area further examines the ordinances with regard to their overall impact. It identifies observed trends relating to their implementation or effectiveness. This section also includes an analysis of the perceptions of relevant public safety professionals.

Study Reporting…

The final phase of the *Public Safety In-Building Ordinances and Their Benefits to Interoperability Report* was study reporting, which included the organization of all collected data into key findings. The study is organized into five parts. The first part is this up-front summary report that reviews the methodology and key findings of the study. The key findings are organized into the four areas identified above. A series of appendixes (A–D) follow the summary report and present comprehensive findings related to specific areas of the study. The data contained within each appendix was used to develop the findings contained within this summary report. A brief description of each appendix follows:

- Appendix A provides an overview of seven existing and four proposed ordinances for in-building communications coverage.

- *Appendix B* details the overall problems related to in-building wireless communications and the specific solutions or equipment available to resolve the issues and comply with the identified ordinances.

- *Appendix C* reviews the financial issues related to implementing wireless communications systems inside buildings.

- *Appendix D* analyzes the development and impact of the codified ordinances.

- *Appendix E* provides a list of common acronyms used throughout this report.

The relationship between the appendixes and the summary report is shown in Figure 2.

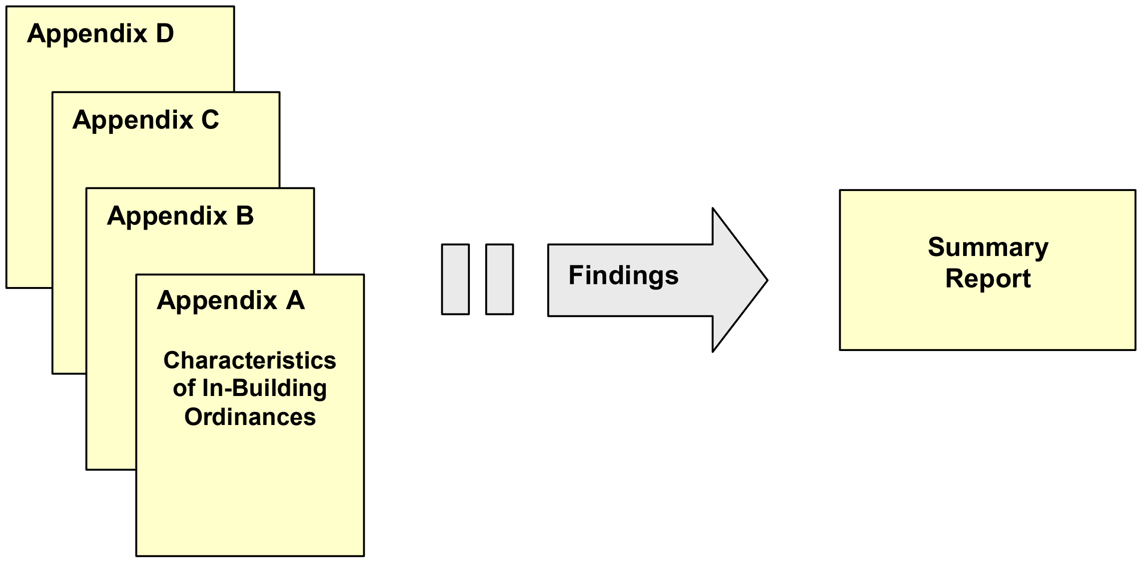

Figure 2
Document Organization

2. KEY FINDINGS

The analysis of in-building ordinances for public safety communications yielded several key findings. The findings are organized into the areas detailed in the study reporting phase of the approach.

2.1 Characteristics of In-Building Ordinances

General…

- Very few jurisdictions have successfully enacted in-building ordinances. Research conducted for this study led to the identification of seven jurisdictions with enacted ordinances and four jurisdictions with proposed ordinances. The jurisdictions are summarized in Table 1.

Table 1
Summary of Jurisdictions

	Jurisdiction	Year Enacted	Ordinance Codification
Codified Ordinances	Boston, MA	2000	Boston, MA, Fire Department Fire Code
	Broward County, FL	1999	Broward County, FL, Code-Telecommunications
	Burbank, CA	1991	Burbank, CA, City Building Code
	Folsom, CA (Sacramento County)	1999	Sacramento County, CA, Uniform Fire Code
	Ontario, CA	1999	Ontario, CA, City Municipal Code
	Roseville, CA	1999	Roseville, CA, City Fire Code
	Scottsdale, AZ	2002	Scottsdale, AZ, City Electrical Code
Proposed Ordinances	Grapevine, TX	N/A	Grapevine, TX, Building Code
	Fairfax County, VA	N/A	Fairfax County, VA, Fire Code or Virginia State Building Code
	Montgomery County, MD	N/A	Maryland State Fire Code
	Sacramento, CA	N/A	City of Sacramento, CA, Fire Code

- Agencies most frequently named in the ordinances are firefighting and law enforcement; some ordinances use more expansive definitions detailing first responders and other users.

- Usually, ordinances are introduced as amendments to a city or county's legal code by a legislative body. In some jurisdictions, it is the legislative body that makes the final decision on whether a measure will be enacted; in others, a referendum is presented to the voters to ultimately approve or reject the measure.

- In-building ordinances are codified within various codes including fire, building, and electrical codes in addition to other statutes. Of the established ordinances studied, three were codified in the fire code, three in the building code, and one in the electrical code.

- Jurisdictions use two different approaches to ensure in-building public safety communications coverage.

  – The first approach is more common and sets specific standards for various technical characteristics of wireless communication.

  – The other type of in-building communications statute is more general, mandating only that structures and facilities must comply with the locality's in-building wireless ordinance, but not specifying much more.

- At least two ordinances (Boston and Roseville) may have been drafted specifically to address limited communications coverage within high-rise structures.

- Research did not lead to any proposed or enacted ordinances or laws governing in-tunnel public safety wireless communications. This may be because most in-tunnel areas are partially or wholly owned and operated by municipalities, and there is no apparent need for a municipality to make binding requirements for its own in-tunnel communications. However, even in cases where the tunnels are publicly owned or operated, ordinances may be used to set wireless communications standards and guidelines. The in-building ordinances identified in this report could provide a model for such in-tunnel ordinances.

Technical Requirements and Solutions of In-Building Ordinances…

Common Technical Requirements of In-Building Ordinances	
Signal Strength	Most in-building ordinances include minimal signal strength requirements of either –95 or –107 dBm.
Coverage and Reliability	Most in-building ordinances require that between 85 and 95 percent of a building floor space in a building is provided with adequate coverage. In addition, all in-building ordinances require that coverage be available between 90 and 100 percent of the time.
Allowed Technical Solutions	Most in-building ordinances allow and recommend the use of passive and active amplification systems such as leaky coax, antenna systems, and bi-directional amplifiers.

- Most ordinances specify the kind of communications system used by the public safety agency or agencies within that jurisdiction. Those ordinances specifically delineate the channels that must not be obstructed or otherwise subject to interference.

- For measuring signal strength, many of the ordinances use a value of –107 dBm. Three jurisdictions use a substantially higher standard of –95 dBm for meeting compliance levels specified in those laws.

- Bi-directional amplifier (BDA) systems are usually the recommended method for meeting the threshold for signal strength required in these ordinances. In many instances, radiating coaxial cable ("leaky" coax) and antenna systems are both permissible solutions.

- The ordinances also typically detail reliability and coverage in two components.

  - The first mandates that a certain percentage of a building, or each floor of a building, must be reached by a radio signal from the public safety wireless system a certain percentage of the time.

  - The other measure is based on an overall percentage of the time that the signal could be successfully accessed in the building.

- Backup generators are required in eight of the jurisdictions surveyed, with a minimum requirement of 12 hours of battery-powered continuous operation without external power input required in six of the jurisdictions researched for this study.

- Many ordinances also regulate the frequency and responsibility for system maintenance and testing. Testing is first performed upon completion of installation of a system. After initial testing, the municipality's users undertake the subsequent annual review usually specified within the ordinances.

  - In addition to annual tests, 5-year tests are required in the County of Sacramento, California; the City of Roseville, California; as well as in the Boston, Massachusetts, in-building radio specification.

  - The cities of Ontario and Burbank, California, two of the jurisdictions surveyed that have passed in-building communications ordinances, also allow for spot field-testing by police or fire department personnel.

Enforcement of In-Building Communications Ordinances…

- As a rule, in-building communications ordinances may not be applied to buildings retroactively. Therefore, these ordinances impact only those buildings constructed after the law becomes effective, and in some jurisdictions, are also relevant in cases in which an existing structure undergoes any modification that increases its size by a certain percentage, typically 20 percent, of its square footage area.

- Although only specifically discussed in three jurisdictions' ordinances (Roseville, Sacramento County, and Boston), and one draft ordinance (the City of Sacramento, California), the responsibility for meeting the requisite standards in all cases implicitly falls on the building owner.

- Five of the jurisdictions studied also incorporate penalties in the ordinances to deter owners and occupants from failing to meet in-building wireless communication requirements.

  – One penalty for non-compliance with these measures is loss of occupancy certification, which would withhold the building or fire code inspector's permission to allow any habitation until the building passes inspection.

  – The Scottsdale, Arizona, ordinance also provides for a fine of up to $1,000 for violation of the public safety radio amplification ordinance.

  – The proposed Grapevine, Texas, ordinance would carry a fine of up to $2,000 per day for violation of that city's regulations.

- Some of the ordinances that have been enacted limit the kind of structures to which their requirements apply.

  – Many jurisdictions do not require coverage in residential areas or for buildings constructed with wooden frames.

  – Other jurisdictions limit application of in-building communications ordinances to structures above a certain height (30–35 feet) or a certain area (5,000 square feet or more).

  – New additions to buildings that would otherwise be covered within the terms of these ordinances are not required to comply with in-building communications standards if the improvements do not increase the total area of the structure by 20 percent or more.

2.2 Technology Issues

- Three solutions are typically implemented to improve in-building communications either as standalone solutions or together in various components of a system: radiating coaxial cable, internal antenna systems, and BDA systems.

  – Radiating cable or "leaky coax" functions like a continuous antenna. It is outfitted with controlled slots in the outer conductor that allow radio frequency signals to be coupled between the coax cable and its surrounding environment.

  – Internal antenna systems consist of small antennas strategically located throughout a building.

  – A BDA system increases the signal level for talk-back or talk-out coverage improving communications inside the building. The system is composed of a donor antenna, internal coverage antenna(s), and BDA(s).

- Future technology, such as ultra wideband, may help improve in-building communications issues. However, these technologies are still in developmental stages and their future impacts remain unknown.

2.3 Financial Issues

General…

- A wide variety of public and private structures may require the installation of in-building systems to enhance the coverage of public safety wireless networks. These include shopping malls, casinos, and convention centers; airports, stadiums, and museums; office buildings, factories, and utility plants; hospitals and hotels; and apartment complexes and other large residential buildings.

- The type of building, along with the size and shape, layout, and building materials used in construction can affect the need for and cost of an in-building solution. Although an airport terminal and office building may have the same area and may be constructed of the same materials, the office space may require a much more complex solution to provide coverage throughout the building because of its design and layout.

Factors Affecting the Cost of In-Building Solutions…

- Timing of the design and installation of the solution also affects the cost. Typically, it is more expensive to retrofit a building with a solution than to install the system during building construction.

- The severity of the in-building coverage problem also influences solution cost. Not every building requiring wireless access improvements will require enhancements throughout the entire building. The cost of the solution for each building depends on the specific circumstances of that building.

Cost Estimates for Typical In-Building Solutions…

- Each building and situation is unique and requires tailored in-building solutions. Based on market research, a 45,000 square foot floor of a building could be covered with 300 feet of radiating cable for a total cost of $5,230. An active BDA system could be installed in a 200,000 square foot area, such as a warehouse, for approximately $33,000.

- The highest cost in-building solutions are those required for very large buildings in urban environments. According to one vendor in the industry, "it would cost approximately $19,000 to cover a 20,000 square foot, one-floor structure, while covering a five-floor, 400,000 square foot structure would cost approximately $65,000."

- The uncertainty associated with costs for urban in-building solutions is a major concern associated with current and proposed ordinances.

- A recent report on public safety wireless communications, entitled "Increasing FDNY's Preparedness"[1] dealt with this issue. The report makes several recommendations regarding its finding that in-building communications during the emergency response at the World Trade Center was poor. The report estimates the cost of outfitting high-rise buildings taller than seven stories in New York City with in-building solutions at $0.30 to $0.60 per square foot. According to the estimate, to install an in-building system in one major high-rise is between $1 million and $2 million. Clearly, the requirement for building owners to pay for in-building systems will not be distributed equitably because not all buildings will require multimillion dollar in-building solutions.

2.4 Development of In-Building Ordinances

General…

- There were several reasons localities established in-building communications ordinances. One of the primary reasons was the adoption of ultra high frequency (UHF) systems (including 800 megahertz [MHz] systems), and efforts to resolve problems that were detected as these new systems were implemented and used. All of the ordinances related to public safety wireless communications were passed because there was at least a perceived need to compel property owners to provide access, or at least not prohibit access, to the public safety wireless networks.

- All of the identified jurisdictions with ordinances use systems manufactured by the same company, Motorola. This may be because Motorola built a majority of the local government public safety wireless networks.

- Most of the jurisdictions that adopted ordinances to improve in-building coverage operate in the UHF band (including 800 MHz). However, one ordinance applies to both UHF and very high frequency (VHF) systems.

- There does not appear to be a correlation between the establishment of ordinances and whether systems are trunked, digital, or encrypted.

- The jurisdictions with codified ordinances passed those laws after installing new wireless communications systems. The timing of the ordinances and the type of systems installed may lead to the conclusion that many newer systems were not designed to meet public safety requirements for communications inside buildings. Ultimately, the community pays for the cost of in-building solutions either by building developers or direct government expenditures. Ordinances do not shield localities or public safety organizations from the overall system cost.

[1] *Increasing FDNY's Preparedness*, August 19, 2002, commissioned by the New York City Fire Department following the September 11, 2001, attack on the World Trade Center. The complete report is available at http://www.nyc.gov/html/fdny/html/mck_report/toc.html

– In-building coverage can be provided for almost any environment if enough radio sites are included in the network infrastructure. However, because of cost and other issues, system designers sometimes must compromise between operational requirements and practical financial concerns.

– When procuring new systems, agencies did not consider the cost of the in-building solutions as part of the overall system cost. It is unclear whether public safety agencies knew that they were procuring networks that would not provide adequate in-building coverage.

– Even where in-building ordinances were adopted by the locality, the local governments still paid for some of the in-building solutions. This is especially true for government buildings. Therefore, the financial burden of the in-building solutions must be supported by the community either through direct government expenditures or unfunded mandates to support in-building ordinances.

– In cases in which public safety professionals procuring the system knew that they would not have adequate in-building coverage with the proposed network infrastructure, they could have included in-building solutions as part of their overall system development plan.

– A lower cost network infrastructure could result in the need for countless in-building solutions. If this issue was addressed before the system was procured, a system could have been procured based on its true overall cost. Therefore, the cost of the in-building systems, even if paid for by property owners, should be considered part of the actual system cost.

Drafting In-Building Ordinances…

- There are common methods and language for drafting in-building ordinances. Several professionals stated that established in-building ordinances from other jurisdictions were used to draft the ones for their own localities. By reviewing the ordinances, it is clear that several ordinances use almost identical format, structure, and language.

- According to research completed for this study, in-building wireless communications ordinances first became the topic of legislative initiatives to provide standard coverage levels for public safety wireless users in California cities. The first in-building communication ordinance was passed and codified in 1991 and is found in the Burbank, California, *City Building Code*.

Challenges to In-Building Ordinances…

- The 11 jurisdictions researched for this report were either successful in implementing in-building requirements through the legislative process within their community, or are in various stages of development and attempting to acquire political support and public approval to provide better communications for public safety personnel.

  - Several jurisdictions attempted to pass ordinances creating obligations for building management, tenants, construction firms, and developers to adhere to standards for wireless communications coverage for public safety officials inside buildings. In some of those cases, they have met significant opposition from builders and real estate developers eager to contain construction costs.

- Other jurisdictions that have attempted to pass such ordinances have failed. In those cases, political support for regulating new and existing wireless communications systems was insufficient to overcome resistance from builders and developers, who argued that implementing such measures would create greater expense and difficulty than they could afford.

  - One jurisdiction has been trying to pass an ordinance since at least 2000. Champions of the legislation include public safety agencies and the City Manager's Office. However, the legislation has been tabled because of opposition from builders and developers due to the financial burden the ordinance may place upon the building community.

  - In another area of the country, because of the substantial influence of developers, a proposed ordinance was not well received among local elected officials, who had initially endorsed the measure to aid public safety personnel and other first responders.

  - In contrast to legislative solutions, informal working arrangements exist that may help to provide coverage in many areas where ordinances have not been enacted.

- Typically, once a law concerning public safety wireless radio communications has been codified, there is very little resistance to compliance with the law. The research team found no instances of building owners, developers, or other interested parties challenging the in-building communications ordinances once they were enacted.

2.5 Perceptions and Benefits of Ordinances

General…

- The information on the success and failure of each ordinance in improving the quality of in-building public safety wireless communications is limited. Most of the evidence of successfully obtaining cooperation and compliance from builders, developers, commercial mobile radios service carriers (CMRS), and other stakeholders is anecdotal, and experiences vary drastically from jurisdiction to jurisdiction.

Perceptions…

- During the course of gathering data for this study, public safety professionals in jurisdictions with in-building communications ordinances provided their impressions and perceptions of how well the ordinances have performed.

  – The most important effect of in-building communications ordinances is that in those localities where ordinances were established, they have successfully motivated building owners to install in-building solutions to enhance public safety coverage.

  – Most of the ordinances have very specific guidelines for testing buildings to ensure that they meet the minimum technical standards; however, not all localities follow these testing and enforcement procedures.

- None of the public safety professionals that were contacted for this study were aware of any direct or indirect impacts on interoperability related to in-building ordinances. However, none of the past, current, or expected interoperability initiatives are related to in-building ordinances.

- The research team also observed a wide discrepancy between jurisdictions regarding awareness among public safety personnel, as well as among the construction and development community, with respect to the enactment of regulations that govern the quality of in-building communications.

- There is a perception among some officials within the public safety community that builders' and developers' interests are typically more focused on short-term costs. Under current market conditions, it would be difficult to mandate any measures that require greater investment than the commitments that they have already made.

Interoperability Benefits…

- Based on the data gathered for this study, in-building ordinances have no noticeable impact on interoperability between public safety organizations. This finding is based on the perceptions of the interested public safety professionals, an analysis of the types of systems used in the localities, and the specific requirements set forth in the in-building ordinances.

  – The primary measure of interoperability between disparate wireless networks is how well they interoperate throughout their coverage area, not inside any individual building.

  – The interoperability impact of any particular in-building solution would be minimal unless the overall systems were already interoperable through a patch, switch, or other method that relied on the separate network infrastructures. If ordinances ensure that subscriber units from each system maintain access under their network infrastructure while in the building, then the established interoperability link would work as usual.

APPENDIX A—CHARACTERISTICS OF IN-BUILDING ORDINANCES

APPENDIX A—CHARACTERISTICS OF IN-BUILDING ORDINANCES

The *Public Safety In-Building Ordinances and Their Benefits to Interoperability Report* assesses the ability of laws, regulations, and ordinances to effect the development of in-building wireless systems that mitigate or resolve the problem of public safety in-building wireless communications. An essential component of this study is to examine the ordinances that have been established or proposed by public safety or other government entities. The purpose of this appendix is to review the content of these ordinances and overall trends that the Public Safety Wireless Network (PSWN) Program research team identified.

A.1 Background and Purpose of Investigation and Analysis

The purpose of this study was to examine the number and kinds of regulations pertaining to the provision of in-building and in-tunnel communications that were codified or contemplated. The first step was to determine the specific ordinances that were enacted and to review the state of the law as it exists today with respect to in-building public safety wireless communications, examining the steps taken to ensure that public safety wireless networks meet the operational requirements of the user community. The research team conducted this review to learn about the legislation that currently exists or has been considered, and to identify the trends in the laws related to resolving in-building coverage issues.

This study examined seven jurisdictions that successfully implemented regulations to promote quality of service for wireless communications systems used by area public safety personnel. These jurisdictions included—

- City of Boston, Massachusetts
- Broward County, Florida
- City of Burbank, California
- City of Folsom (Sacramento County), California
- City of Ontario, California
- City of Roseville, California
- City of Scottsdale, Arizona.

The agencies most frequently named in these ordinances are firefighting and law enforcement; however, some ordinances, such as those in Burbank and Roseville, use more expansive definitions detailing first responders and other users (i.e., "including, but not limited to, firefighters and police officers"). Other jurisdictions, such as the City of Sacramento, allow shared use of the 800 megahertz (MHz) system by fire, police, emergency medical services, public works, and other public safety personnel. In that particular jurisdiction, it is notable that many agencies share in a regional communications system that was jointly purchased by several cities within Sacramento County. Those cities that did not initially contribute have since made arrangements to contribute fees for service in exchange for shared use of the network infrastructure and facilities.

This study also reviewed the status of ongoing efforts in four other areas that are in the process of introducing legislation that would regulate in-building communications systems. These areas included—

- City of Grapevine, Texas
- Fairfax County, Virginia
- Montgomery County, Maryland
- City of Sacramento, California.

These jurisdictions are at various stages of developing ordinances that detail the responsibilities of building owners and developers to accommodate public safety wireless communications. While some jurisdictions are still in the preliminary stages, Montgomery County held a public hearing regarding a proposed amendment to the Maryland State Fire Code on August 13, 2002, to generate support for the adoption of this measure. Fairfax County has developed a white paper that recommends mandating signal strength, reliability of coverage, and other measures of wireless communication properties.

A.2 Approach

In performing the research on these ordinances, the research team used multiple disciplines and resources. Data gathering typically consisted of two main parts, identification of localities with ordinances and follow-up data gathering to learn about the specific ordinance. In some cases, because of current developments in some of the jurisdictions where new regulations are being proposed, the research has been ongoing, with this report containing the most recent information.

Online Research. The research team made extensive use of various electronic research services to gather data regarding local ordinances that govern in-building and in-tunnel communications. Legal databases, including the Cornell University Online Law Library, the Emory University Online Law Library, Westlaw, and Lexis/Nexis, were all researched to locate jurisdictions with relevant regulations. However, most legal research databases are geared toward case law, and federal and state statutes. These resources had very few city and county ordinances contained in their respective databases. Other general online research tools and search engines, including Alta Vista, Ask.com, Google, and Yahoo!, yielded more information that identified jurisdictions with existing or proposed in-building ordinances.

Public Safety and Government Associations. The research team performed additional research by making personal contacts through e-mail inquiries, telephone conversations, and other interaction with various professional public safety and government communications experts, including the Association of Public-Safety Communications Officials-International, Inc. (APCO), the International Association of Fire Chiefs, the National Association of Counties, The National League of Cities, the National Telecommunications and Information Administration, and other groups, including contacts made via PSWN Program outreach efforts. The team also made inquiries about these ordinances through Allen Communications Research, a private research organization engaged by the PSWN Program to conduct communications research on issues concerning public safety on the Federal Communications Commission's (FCC) rulemaking dockets.

Local, State, and National Uniform Codes, Models, and Standards. The research team also reviewed various text sources, including the National Fire Protection Association International's

Fire Prevention Code, *Code for Safety to Life from Fire in Buildings and Structures*, and *National Electrical Code*. The research team consulted village, city, and county statutes and additional authorities to determine where ordinances had been established or proposed. Analysts examined these sources to determine whether a "model" statute existed that was being used as a blueprint for those ordinances that had been proposed or adopted. Although these sources did not explain the similarities between several of the ordinances examined, other research would determine that the common characteristics resulted from a comparison and imitation of ordinances successfully adopted by predecessors.

Surveys and Interviews. Finally, the research team conducted interviews with knowledgeable communications personnel in the 11 jurisdictions identified as having established or proposed ordinances. In many cases, the team consulted several different participants in the information gathering process because they had experience with different aspects of the system. To facilitate the interview process, the research team prepared a survey. The questions were developed to collect information about different aspects of the jurisdiction's radio systems and efforts to pass ordinances to protect and promote quality of service for in-building communications. Many local fire and law enforcement personnel provided information that was used in the preparation of this report, and their observations and insights are the foundation for many of the findings presented in this report.

Among the topics addressed in the survey were questions regarding system infrastructure, system users, coverage, communication problems, and issues that the system was designed to correct or improve. Other data collected indicated the effectiveness of the systems, as well as the results of efforts to enact ordinances to govern the in-building communications systems operated by public safety agencies. In some cases, participants in the survey were involved in the ordinance drafting and passage process, while others were actively involved in the use of the communications facilities. Each interviewee was asked a variety of questions that required familiarity with the background of that jurisdiction's ordinance, the system that is in use in that particular area, and the coverage problems experienced that were the impetus for any effort to codify in-building communications standards.

A.3 Sources of Authority

Usually, ordinances are introduced as amendments to a city or county's legal code by a legislative body; the public is given notice of those proposed laws and the opportunity for comment and debate. In some jurisdictions, it is the legislative body that makes the final decision on whether a measure will be enacted; in others, a referendum is presented to the voters to ultimately approve or reject the measure. This procedure varies with the subject matter of the bill or issue and can depend on a variety of factors, including whether separate appropriations will be required to implement the proposed act. This section of the report examines how the laws that regulate in-building communications were passed and identifies the source of the authority for rulemaking in several different jurisdictions.

Formal rulemaking requirements contained in city or town charters, state and federal constitutions, and other enabling legislation that grants a particular office, agency, or group of elected or appointed officials the authority to make binding law in that jurisdiction will determine the procedure to be observed in each case. How procedures are determined is not uniform within the individual states—each locality has its own independent procedures and rules that differ from surrounding jurisdictions, based on how that area was organized, e.g., via a charter, articles of incorporation, or other designation by law. This variation makes classifying and organizing each jurisdiction's rules difficult, and frequently redundant laws are on the books that overlap, conflict, or that are enforced by competing authorities.

The research conducted for this study confirmed that most of the ordinances that have been codified were passed by local legislative authorities. Sacramento's 800 MHz building amplification ordinance was adopted by the County Board of Supervisors. The City Council of Ontario amended the Municipal Code of that city to require in-building coverage for the city's 800 MHz public safety communication systems. The Board of County Commissioners in Broward County passed the signal obstruction ordinance in that jurisdiction, and the City of Scottsdale's code was amended by the City Council to adopt and revise public safety radio coverage requirements.

Boston diverged from this pattern drastically by adopting an executive rule amending the city's Fire Code unilaterally. A copy of this rule, posted on the RFSolutions.com database (maintained by the Jack Daniel Company), notes that "this fire code is unique because of agency-specific content that may not be applicable to others." The In-Building Radio Specification, modifying fire alarm order 93-1, has the same force of law as the ordinances passed by legislative bodies in different jurisdictions.

A.4 Identification of In-Building Communications Ordinances

The research team's preliminary analysis identified seven jurisdictions nationally that had successfully passed in-building communications ordinances. Based on research conducted for this study, the first jurisdiction to regulate in-building coverage was Burbank in 1991. The cities of Roseville and Ontario passed similar legislation in 1999, as did Sacramento County and Broward County. In addition, at a later date, Ontario passed a second ordinance that, like Broward County's ordinance, generally prohibited interference to public safety communications. In 2000, the City of Boston's Fire Code was amended to permit use of wireless communications to provide in-building radio coverage. As stated earlier, four other localities (Grapevine, City of Sacramento, Montgomery County, and Fairfax County) studied are in various stages of ordinance initiatives intended to provide solutions for problems that public safety personnel had experienced with in-building communications coverage.

A.4.1 Types of Ordinances Identified

The ordinances examined in this study reflect a number of different approaches for mandating in-building communications systems and for defining the needs of the agencies that use them for the preservation of life and property. The ordinances are codified in building codes, fire codes, and in other sections of that region's governing laws. Table A-1 summarizes when and where the ordinances in each jurisdiction are codified.

Table A-1
Summary of Codified Ordinances

Jurisdiction	Year Ordinance Enacted	Ordinance Codification
Boston, MA	2000	Boston Fire Department Fire Code
Broward County, FL	1999	Broward County Code-Telecommunications
Burbank, CA	1991	Burbank, CA, City Building Code
Folsom, CA (Sacramento County)	1999	Sacramento County Uniform Fire Code
Ontario, CA	1999	Ontario, CA, City Municipal Code
Roseville, CA	1999	Roseville, CA, City Fire Code
Scottsdale, AZ	2002	Scottsdale, AZ, City Electrical Code

A.4.2 Methods of Regulating In-Building Communications

The research team found that jurisdictions use two different approaches to ensure in-building public safety communications coverage. The first approach is more common and sets specific standards for various technical characteristics of wireless communication, including signal strength, reliability of coverage, and the types of amplification systems that are permitted to meet established levels of performance. These statutes also specify the frequencies on which the in-building public safety communications systems operate. Statutes in the cities of Burbank, Roseville, Sacramento, Scottsdale, and in Sacramento County, as well as the rule found in Boston, all follow this pattern. The draft ordinances in the cities of Sacramento and Grapevine are also modeled on this specific regulatory regime. Ordinances in these jurisdictions typically contain seven similar areas—

- **Types of systems requiring in-building enhancement**—specifies the types of systems used by public safety agencies within the jurisdiction
- **Signal strength**—details the required signal strength in either dBm or milliwatts of power
- **Coverage and reliability**—highlights the percentage of a building or floor that a radio signal must reach and the percentage of time this should occur
- **Technical solutions**—details the type of systems that can be installed inside buildings in order to enhance coverage
- **Testing procedures**—details who performs testing and how often it should occur
- **Enforcement**—specifies penalties for non-compliance with the ordinances, which can range from non-issuance of the Certificate of Occupancy to levying of fines and providing for additional remedies for noncompliance
- **Exemptions**—details requirements for buildings that are not required to comply or meet the standards set forth in the ordinance.

The other type of in-building communications statute is more general, mandating only that structures and facilities must comply with the locality's in-building wireless ordinance, but not specifying much more. The Broward County ordinance and the second of the City of Ontario's two in-building communications ordinances require that area buildings comply with public safety mandates, but do not specify acceptable performance standards. The proposed Montgomery County ordinance is in this vein; however, it is even simpler and more general than the other ordinances that have been enacted.

A.4.3 In-Building Communications Ordinances Codified Within Fire Codes

Three of the regulations that the research team studied for this report, including the ordinance passed in Roseville, the in-building ordinance for Sacramento County, and the City of Boston's in-building radio specification, all codify public safety communications requirements in the state or local fire code. The proposed ordinances for the City of Sacramento and Montgomery County would also be codified in that jurisdiction's fire code, if approved.

Boston's rule requires that builders and developers must use either a hard-wire telephone system for all high-rise structures, or apply for a waiver to use a wireless system that incorporates the Fire Department's ultra high frequency (UHF) wireless system to guarantee in-building coverage. It is not clear whether jurisdictions other than Boston have similar prerogatives to implement standards; however, if an independent agency has the requisite authority to establish such a requirement without some legislative approval, other jurisdictions should be advised to consider this expedited method when contemplating in-building communications ordinances in the future. The Boston Fire Department's in-building radio specification rule also contains administrative procedures that detail the forms to be used, including a letter of notification of acceptance to the property owner. That regulation also instructs the owner regarding the kind of cabinet in which equipment is to be kept, and the type of power supply and circuit that is required for each amplifier that is deployed. Another variation of Boston's rule requires an audible failure alarm to sound when the building's primary system power is rendered inoperable.

The City of Sacramento's draft ordinance is also proposed as a provision for the city's fire code. Communications officials with the Sacramento Metropolitan Fire Department interviewed by the research team felt that in-building communications ordinances should be codified in the fire code, and that centralizing the regulations that applied to construction standards put the developers on notice regarding the requirements that the city expected them to meet. In contrast, under the Sacramento County ordinance, the Sacramento Fire Department provides builders and developers with worksheets and "walks them through" the regulatory approval process because it is common for confusion to occur with respect to the standards that exist and which agencies must be notified to get permits and approval of work.

Montgomery County's proposed ordinance would also amend the Fire Code for the State of Maryland. Montgomery County's in-building ordinance initiative seems to take a hybrid approach to mandating coverage for public safety communications. It combines aspects of Boston's fire alarm order and Broward County's ordinance, and would amend the State of Maryland Fire Code by adopting a broad resolution that requires compliance without imposing specific levels of coverage. The proposed amendment is the most general of the ordinances that the research team examined, stating merely that, "if [a]ny new structure that adversely affects the Montgomery County Emergency communications system within the structure or in the surrounding area [the owner] must provide approved equipment to maintain the minimum level of service." Whether this measure can pass is debatable because such expansive language, without any specific and cognizable standards to measure performance, would arguably be open to arbitrary interpretation and subjective enforcement.

A.4.4 In-Building Communications Ordinances Codified Within Building and Electrical Codes and Other Statutes

Two of the enacted in-building communications ordinances the research team evaluated are codified in the building code of the City of Burbank, and in an amendment to the City of Scottsdale's *Building Electrical Code*. This approach creates a clear duty that it is incumbent on all developers to adhere to these requirements as part of the construction standards that are required for those new buildings not subject to an exemption in those regions.

Some of the ordinances that the research team examined in this study were found in different areas of those jurisdictions' laws. In Broward County, the signal obstruction ordinance is located under "Miscellaneous Offenses and Provisions," in the category of "Telecommunications." One of the ordinances enacted in the City of Ontario; which mandates radio signal strength, testing reliability, types of amplification systems used, and other aspects of in-building communications systems; amends the city's Municipal Code. The other Ontario ordinance creates an effective ban on any wireless systems that cause interference to public safety radio reception.

A.4.5 In-Tunnel Communications Regulations

Research did not lead to any proposed or enacted ordinances or laws that govern in-tunnel public safety wireless communications. Several possible reasons may explain the dearth of information, and action, with respect to ensuring that viable communications exist within tunnels and other underground areas. One reason is that most of these areas are usually partially or wholly owned and operated by the municipality. For example, the provision of mass transit services in various urban areas is provided jointly by the city and a contractor, such as the Bay Area Rapid Transit in San Francisco, California, or by a separate government entity, as is the case with the Washington Metropolitan Area Transit Authority in Washington, DC. The only underground activity that can take place on public property must be authorized by that jurisdiction and performed with that area government's knowledge and acquiescence. There is no apparent need for a city, county, or other municipality to make binding requirements that its own in-tunnel communications operate effectively because the personnel of that government would be the users conducting permitted operations in that area. However, even in cases where the tunnels are publicly owned or operated, ordinances may be used to set wireless communications standards and guidelines. The in-building ordinances identified in this report could provide a model for such in-tunnel ordinances.

A.5 Technical Requirements of In-Building Communications Ordinances

The research team examined ordinances that include a number of common characteristics and provide standards that building owners must evaluate and achieve to ensure effective wireless public safety communications. Some of these indices are summarized in Table A-2. *Appendix B, Technology Issues*, provides a detailed description of these characteristics and the relationship to in-building wireless coverage.

Table A-2
Summary of System Type, Signal Strength, and Reliability

	Jurisdiction	Type of System	Signal Strength	Reliability (%)	Comments
Codified Ordinances	Boston, MA	480 MHz	-95 dBm	95	Local rule passed by Boston Fire Department that is not an ordinance
	Broward, FL	800 MHz	N/A	N/A	Ordinance that only applies to amplification requirements
	Burbank, CA	470 MHz	-107 dBm	90	First documented in-building communication ordinance in the United States
	Folsom, CA (Sacramento County)	800 MHz	-95 dBm	100	---
	Ontario, CA	800 MHz	-107 dBm	90	This city has both a general ordinance and a non-interference ordinance
	Roseville, CA	800 MHz	-95 dBm	100	---
	Scottsdale, AZ	Police—800 MHz Fire—150 MHz	-107 dBm	90	Fire department system is the only very high frequency (VHF) system in that area of the state; all surrounding areas are on 800 MHz band
Proposed Ordinances	Fairfax County, VA	800 MHz	N/A	N/A	County Police Department preparing strategy for submitting to State Assembly for approval
	Grapevine, TX	800 MHz	-107 dBm	95	Also allows for field testing on notice
	Montgomery County, MD	800 MHz	N/A	N/A	Ordinance is being submitted as an amendment to the MD State Fire Code
	City of Sacramento, CA	800 MHz	-95 dBm	90	---

Types of Systems Requiring In-Building Enhancements. Each ordinance specifies the kind of communications system used by the public safety agency or agencies within that jurisdiction. The ordinances specifically delineate the channels authorized for use by the relevant agencies that operate those wireless systems. Typically, fire departments and local law enforcement are involved in the use and access of these facilities. Some jurisdictions, such as Roseville, also allow their wireless communications systems to be used by transportation, public works, and other local officials.

Although the majority of the ordinances the research team evaluated for this report govern the operation of 800 MHz wireless communications, several jurisdictions still actively using VHF and UHF communications systems were also studied and have ordinances that protect operation of those systems. Many jurisdictions with 800 MHz systems also continue to use VHF and UHF equipment for communicating with neighboring jurisdictions, or as a redundant system in case primary communications are rendered inoperable, as mentioned above. Still other jurisdictions have no immediate plans to transition from VHF or UHF systems to an 800 MHz network.

Signal Strength. Signal strength is measured in terms of dBm, defined as decibels referenced to one milliwatt of power. A common minimal signal strength standard in the ordinances is –107 dBm. Three of the jurisdictions studied in this analysis (i.e., Scottsdale, Burbank, and Ontario) use that figure as a baseline measurement for in-building signal strength. Three other areas (i.e., Sacramento County, Roseville, and Boston) use a substantially higher standard of –95 dBm for defining compliance with their respective laws. In its draft ordinance, Grapevine would set the minimum signal at the less stringent level of –107dBm. The City of Sacramento would set the level for signal strength at –95 dBm.

The proposed legislation in Montgomery County does not mention signal strength as a factor in regulating the quality of in-building communications. The white paper report prepared by Fairfax County does not specify signal strength nor does Broward County's ordinance, which requires that a builder provide an easement for a signal booster for buildings taller than 50 feet, if the Broward County Telecommunications Group determines that the prospective construction project will "interfere" with public safety communications. This more general approach is also used in the City of Ontario *Municipal Code*, in Section 9-1.3289, which prohibits interference from existing or future wireless systems to any of the jurisdiction's public safety wireless radio systems. However, as noted above, a second ordinance in that jurisdiction addresses signal strength and other more precise requirements.

Coverage Reliability. Coverage reliability has two components. The first component mandates that a certain percentage of a building, or each floor of a building, must be reached by a radio signal from the public safety wireless system a certain percentage of the time. Seven of the 11 jurisdictions studied provide a baseline figure for this measurement, ranging from a minimum of 85 percent coverage in the cities of Burbank and Ontario to a maximum level of 95 percent coverage in Grapevine's draft ordinance. Some jurisdictions have ordinances that also require that a corresponding signal transmitted from the building being evaluated must be received at a central communications office, or at the nearest communications office, of that jurisdiction.

All of the communications ordinances studied require another indicator of wireless communications system reliability, based on an overall percentage of the time that the signal could be successfully accessed in the building. Reliability indices required under ordinances again range from a low of 90 percent in Scottsdale to a 100 percent achievement level mandated by the City of Roseville and County of Sacramento in their respective ordinances.

Backup Power Supply. Backup generators are required in eight of the jurisdictions surveyed, with a minimum requirement of 12 hours of battery-powered continuous operation without external power input required in six of the jurisdictions researched for this study. The City of Grapevine only requires the battery to run for 8 consecutive hours. In addition, all seven of those jurisdictions further require that "the battery system shall automatically charge in the presence of an external power input."

A.6 Technical Solutions

Different jurisdictions have offered different solutions for eliminating interference that impacts their public safety communications systems when used indoors. No ordinance mandates use of a single technology, but rather allows builders to select from several prescribed means to meet coverage requirements devised by each jurisdiction.

A.6.1 Amplification Systems

As summarized in Table A-3, most of the ordinances surveyed also deal with the subject of the amplification systems that are allowed in order to meet required signal levels and other measures of reliability. All of the California jurisdictions studied, including the proposed ordinance for the City of Sacramento, the proposed ordinance for Grapevine, the Boston Fire Alarm Order, and the Scottsdale, Arizona, ordinance each specifically discuss the amplification systems permitted for in-building communications in those jurisdictions.

Bi-directional amplifiers (BDA) are usually the recommended method for meeting the threshold for signal strength required in these ordinances. In many instances, radiating coaxial cable ("leaky" coax) and antenna systems are both permissible solutions. While none of the ordinances that have been codified or proposed by any jurisdiction mandates the use of BDAs, in two jurisdictions, Boston and Ontario, the ordinances require the use of BDAs if internal antenna systems are the chosen method to improve signal strength to meet in-building requirements. Personnel in one jurisdiction noted that "leaky coax and antenna systems do not provide coverage in high rise structures," and those buildings presented the most persistent challenge for coverage in the jurisdiction. Furthermore, builders and developers also are required to use BDAs to ensure reception in high rises. Officials contacted in the cities of Ontario and Boston also confirmed that high-rise buildings are a primary concern for public safety wireless communications coverage.

A.6.2 Radiating Coaxial Cable

Eight of the 11 jurisdictions studied allow use of radiating coaxial cable, or "leaky" coax to meet signal coverage requirements under proposed or actual in-building communication ordinances.

Table A-3
Summary of Technical Solutions

	Jurisdiction	Amplification Allowed	Radiating Coax Cable	Antenna System	Bi-Directional Amplifier
Codified Ordinances	Boston, MA	√	√	√ BDA Required	Must have if using antenna
	Broward County, FL	N/A			No
	Burbank, CA	√	√	√	With or without BDA
	Folsom, CA (Sacramento County)	√	√	√	With or without BDA
	Ontario, CA	√	√	√ BDA required	Must have if using antenna
	Roseville, CA	√	√	√	With or without BDA
	Scottsdale, AZ	√	√	√	800 MHz or 150 MHz amplifier, as needed
Proposed Ordinances	Grapevine, TX	√	√	√	With or without BDA
	Fairfax County, VA	N/A	N/A	N/A	N/A
	Montgomery County, MD	N/A			States only that the owner or developer must "provide approved equipment" to meet standards for reception
	Sacramento, CA	√	√	√	With or without BDA

A.6.3 Internal Multiple Antenna Systems

Many jurisdictions also authorize the use of internal multiple-antenna systems in order to reach adequate levels of signal strength to meet reception requirements for in-building public safety communications. In 8 of the 11 jurisdictions the research team analyzed, ordinances specifically permit the use of internal antennas to improve the signal quality of wireless public safety radio communication systems. Although none of the ordinances that have been codified or proposed by any jurisdiction mandates the use of BDAs, in two jurisdictions, Boston and Ontario, the ordinances require use of BDAs if internal antenna systems are the chosen method to improve signal strength to meet in-building requirements.

A.7 Buildings Covered by In-Building Communications Ordinances

As a rule, in-building communications ordinances may not be applied to buildings retroactively. Therefore, these ordinances impact only those buildings constructed after the law becomes effective, and in some jurisdictions, are also relevant in cases in which an existing structure undergoes any modification that increases its size by a certain percentage, typically 20 percent, of its square footage area. This can create an issue regarding the treatment of buildings that were built prior to the passage of the ordinance. It is important to note that many older structures do not present as many hurdles for wireless communication coverage as new buildings. Modern materials, such as reflective window glass, or steel-reinforced concrete used in the construction of high-rise buildings, cause attenuation of radio signals, presenting added challenges to providing a universal wireless solution for a community.

Because of cost, coverage, and other factors that impact the provision of wireless public safety communications systems, some jurisdictions must necessarily prioritize targeted buildings and services that are the primary focus of these resources. Hospitals, or areas within hospitals, such as emergency rooms, present a particular challenge. Shopping malls; schools; and local, state, and federal government buildings; as well as significant utilities and critical infrastructure, such as electric power plants, reservoirs, and water treatment facilities; are also considered as primary recipients of guaranteed in-building wireless coverage. For example, in Montgomery County, it was originally planned that the in-building coverage requirements would be extended to more than 90 buildings in the region. By removing local firehouses from the required standards, this figure was scaled back to provide coverage for Montgomery County hospital emergency rooms; government offices; the Washington Suburban Sanitary System, a local water treatment center; schools; police stations; and shopping malls. If that county's ordinance were eventually adopted, these buildings would be the focal points in ensuring that coverage standards are met.

A.7.1 Testing of In-Building Communications Systems

Many ordinances also regulate the frequency and responsibility for system maintenance and testing. Testing is performed initially upon completion of installation of a system. In five of the communities studied, the first systems check and certification of in-building wireless communications capabilities is performed by employees of that municipality, or with those employees present. Three others require the owner to certify that the levels for coverage are attained. It is interesting to note that in all of those jurisdictions (Sacramento County and Roseville, as well as in the draft ordinance for the City of Sacramento), the statutes provide for entry to perform field-testing by local police and fire department personnel. Testing requirements are summarized in Table A-4.

After initial testing, the subsequent annual review usually specified within the ordinances is undertaken by the municipality's users (for example, the local fire departments in 7 of the 11 jurisdictions examined in this investigation). Annual tests are commonly required after the system is certified for operation by the jurisdiction's chosen authority. This is the case in six of the seven jurisdictions that have passed in-building ordinances (all areas except Broward County). In addition, the draft ordinance for the City of Sacramento also provides for annual testing.

In addition to annual tests, 5-year tests are required in three jurisdictions' ordinances. Five-year testing is mandated in the ordinances passed in Roseville and Folsom (Sacramento County), and in the Boston in-building radio specification. It is also mentioned in the draft regulation under consideration in the City of Sacramento.

Several jurisdictions specify that in-building communications system testing may be performed by APCO, National Association of Business and Educational Radio (NABER), or Personal Communications Industry Association (PCIA) certified technicians. This provision is specifically included in the ordinances passed in Roseville and Folsom (Sacramento County) and is mentioned in the draft regulation under consideration in the City of Sacramento. Boston's in-building rule requires that technicians are certified FCC General Radiotelephone license holders.

Table A-4
Summary of Testing Requirements

Jurisdiction	Certification Testing	Annual Testing	Five-Year Testing	Field Testing	Qualifica-tions	Owner Liability
Boston, MA	YES—test overseen by Boston Fire Department Radio Shop	YES—Owner	YES—Owner	NO	YES—FCC General Radio-telephone license	YES
Broward County, FL	NO	NO	NO	NO	NO	NO
Burbank, CA	YES—City of Burbank employees	YES—Burbank Fire Depart-ment	NO	NO	NO	NO
Folsom, CA (Sacramento County)	YES—Owner	YES—Owner	YES—Owner	YES—Local Police & Fire Departments	YES—APCO/PCIA certified	YES
Ontario, CA	YES—City of Ontario employees	YES—Ontario Fire Depart-ment	NO	YES—Ontario Police & Fire Departments	NO	NO
Roseville, CA	YES—Owner	YES—Owner	YES—Owner	YES—Ontario Police & Fire Departments	YES—APCO/ NABER certified	YES
Scottsdale, AZ	YES—Installer with agent of City of Scottsdale	YES—Scottsdale Police & Fire Departments	NO	NO	NO	NO
Grapevine, TX	YES—City of Grapevine employees	YES-Grapevine Fire Department	NO	YES-Grapevine Police & Fire Departments	NO	NO
Fairfax County, VA	N/A	N/A	N/A	N/A	N/A	N/A
Montgomery County, MD	N/A	N/A	N/A	N/A	N/A	N/A
Sacramento, CA	YES—Owner	YES—Owner	YES—Owner	YES—Sacramento Police & Fire Departments	YES—APCO/ NABER certified	YES

Although only specifically discussed in three jurisdictions' ordinances (Roseville, Sacramento County, and Boston), and one draft ordinance (the City of Sacramento), the responsibility for meeting the requisite standards in all cases implicitly falls on the building owner. In one particular jurisdiction, a participant in the survey confided that the annual testing specified in the ordinance was not performed because of a shortage of personnel and funding for verifying compliance. In another jurisdiction, a recently hired communications officer stated that the majority of his responsibilities were to test local buildings for compliance with the area's in-building coverage ordinance.

The cities of Ontario and Burbank, two of the jurisdictions surveyed that have passed in-building communications ordinances, also allow for spot field-testing by police or fire department personnel. The Ontario statute specifies that testing can be performed even if consent is withheld "after obtaining lawful authority" for entry onto the premises (e.g., a warrant). The ordinance in Sacramento County permits field-testing on "reasonable" notice to the owner, as is the case in the Burbank ordinance. The draft ordinance proposed in Grapevine also allows field-testing by police or fire department personnel on that basis.

A.8 Enforcement of In-Building Communications Ordinances

Although the ordinances serve as an initial restriction on applications that would interfere with wireless public safety communications operations, provisions also must be made for regular evaluation of systems to determine whether conditions remain acceptable for indoor wireless communications coverage after a building is completed. Most of the jurisdictions studied in this report have required testing to be performed after the initial acceptance permit is granted. Some jurisdictions specify annual testing, while others may have additional requirements for a 5-year test. Three jurisdictions allow unscheduled field-testing by local police or fire personnel.

Not all buildings are necessarily required to comply with in-building communications ordinances. Residences and other structures may be exempt, depending on the type of building and how it is described in each jurisdiction. For buildings that are subject to these ordinances, some jurisdictions also include a review process in the relevant statute and empower authorized individuals to review and approve testing procedures. Broward County's ordinance recommends (but does not require) that any person planning to construct a building within that jurisdiction that exceeds 50 feet in height should seek review by the Broward County Telecommunications Group to ensure compliance with its ordinance. Some of these ordinances include provisions that describe specific penalties that apply when buildings do not pass scrutiny. The penalties vary with jurisdiction.

A.8.1 Penalties

Five of the jurisdictions studied also incorporate penalties in the ordinances to deter owners and occupants from failing to meet in-building wireless communication requirements. One of the proposed ordinances, the draft in-building communications ordinance for Grapevine, also includes a provision penalizing noncompliance.

One remedy for non-compliance with these measures is loss of occupancy certification, which would withhold the building or fire code inspector's permission to allow any habitation until the building passes inspection. This method of enforcement is used in the Burbank and Ontario jurisdictions, as well as in the cities of Scottsdale and Boston. Other sanctions include fines, and even a criminal misdemeanor conviction, carrying the possibility of imprisonment for up to 6 months for violators of Scottsdale's in-building communications ordinance. That ordinance also specifically authorizes the city to "institute any appropriate action or proceedings to restrain, correct, or abate any violation of this code."

The Scottsdale, Arizona, ordinance also provides for a fine of up to $1,000 for violation of the public safety radio amplification ordinance. The proposed Grapevine ordinance would carry a fine of up to $2,000 per day for violation of that city's regulations. In Broward County, unique enforcement provisions of its signal booster ordinance allow the Board of County Commissioners to enjoin construction projects that fail to comply with the code as "a nuisance because it threatens the health, safety, and welfare of residents and visitors." That ordinance, like the Scottsdale ordinance, also authorizes the pursuit of other unspecified legal remedies by appropriate agencies. The Roseville ordinance does not specify any penalties for non-compliance; however, the city uses "umbrella" clause provisions detailing penalties that are applied from other sections of city's code. The Ontario ordinance prohibiting interference also treats violations as a "public nuisance per se," and requires suspension of any wireless operations by any facilities that are found to create interference with local public safety systems. A summary of the penalties set forth in the ordinances is detailed in Table A-5.

Table A-5
Summary of Penalties

	Jurisdiction	Penalties
Codified Ordinances	Boston, MA	YES—Loss of Occupancy Permit
Codified Ordinances	Broward, FL	YES—Injunction; Other remedies
Codified Ordinances	Burbank, CA	YES—Failure to meet standard for signal strength causes city to withhold certificate of occupancy permit
Codified Ordinances	Folsom, CA (Sacramento County)	NO
Codified Ordinances	Ontario, CA	YES—Can shut down communications operations, loss of occupancy permit
Codified Ordinances	Roseville, CA	NO—Use penalties from other section of fire code
Codified Ordinances	Scottsdale, AZ	YES—$1,000 fine, 6 months jail, loss of occupancy permit
Proposed Ordinances	Fairfax County, VA	N/A
Proposed Ordinances	Grapevine, TX	YES—$2,000 fine per day
Proposed Ordinances	Montgomery County, MD	NO
Proposed Ordinances	City of Sacramento, CA	NO

A.8.2 Exemptions From the Law

Some of the ordinances that have been enacted also limit the kinds of structures to which their requirements apply. Many jurisdictions do not require coverage in residential areas or for buildings constructed with wooden frames. Other jurisdictions limit application of in-building communications ordinances to structures above a certain height (30–35 feet) or with an area of a certain square footage (5,000 square feet or more). Also, new additions to buildings that would otherwise be covered within the terms of these ordinances are not required to comply with in-building communications standards if the improvements do not increase the total area of the structure by 20 percent or more. These different provisions vary with the jurisdiction, and may be accounted for by variations in topography, coverage area, degree of urban development, and the types of systems (whether VHF, UHF, or 800 MHz) that are being used.

APPENDIX B—TECHNOLOGY ISSUES

APPENDIX B—TECHNOLOGY ISSUES

The Public Safety In-Building Ordinances and Their Benefits to Interoperability Report assesses the ability of laws, regulations, and ordinances to effect the development of in-building wireless systems that mitigate or resolve the problem of public safety in-building wireless access. An important component of this study is to assess the difficulties and problems related to in-building wireless communications and the available methods and applications for solving those problems. The ordinances identified by this study do not necessarily require a particular solution for compliance. However, each ordinance does require some level of support for in-building communications if the building hinders access to the public safety wireless system. To help the reader understand and evaluate the actions specified in the identified ordinances, this appendix presents a basic description of the overall problems related to wireless communications inside buildings and the specific solutions or equipment available through the marketplace to resolve those problems. If greater technical detail on the subject is desired, a more detailed description of the issues can be found in the *In-Building/In-Tunnel User Considerations* report available through the Public Safety Wireless Network (PSWN) Program.

B.1 Approach

The approach for developing this report was to identify those topics specifically related to in-building ordinances and to develop documentation that would provide the reader with the necessary background for understanding the technical issues involved.

B.1.1 Technical Review

To develop this part of the study, the PSWN Program research team reviewed a variety of academic, technical, and trade publications to ensure that the scope of the in-building problem was evaluated and documented. The research team conducted interviews with several technical, operational, and industry experts to ensure that the key points were identified and explained. As mentioned previously, the PSWN Program has performed related studies, and this information is consistent with those findings.

B.1.2 Market Survey

To provide a comprehensive view of the types of equipment and hardware available for resolving in-building wireless problems, the research team interviewed several manufacturing and installation representatives. Most of these interviews focused on discussing the products currently available in the marketplace.

B.2 Public Safety Wireless Networks Overview

To properly explain the problems associated with in-building communications, it is necessary to first explain the key aspects of wireless networking. The basic parts of a typical public safety wireless network include network infrastructure (i.e., towers, antennas, repeaters, landlines, microwave links, and base stations) and subscriber units (i.e., portable and mobile radios). In general, communication via a wireless network is usually accomplished by using the network infrastructure to distribute messages from subscriber units dispersed over a large area. For users within the network coverage area, when a user transmits a message from a subscriber unit, the message is received and then retransmitted (or broadcast) by the network infrastructure. Because of the network retransmission, the message can be received by a larger number of subscriber units than would otherwise be possible. This is because many subscriber units within the coverage area of the network infrastructure may not have been within range of each other. Wireless networks use a wide variety of protocols, modulation schemes, and configurations to accomplish this task. The common characteristic of all these methods is the radio frequency (RF) signal. The RF signal carries the message from the subscriber unit that must be received by the network infrastructure for successful communication to occur, and vice versa.

In addition to using the network infrastructure to link subscriber units, public safety users also communicate directly from subscriber unit to subscriber unit. In that case, the subscriber units transmit directly to each other without the use of a network infrastructure. This method is sometimes referred to as "talk around," "simplex," or "single channel" communications. Although this is an effective and necessary method of conducting wireless communications in the public safety environment, it is not the focus of this report. Subscriber unit to subscriber unit communications encounter in-building communications problems similar to those encountered when the network infrastructure is used. However, the ordinances that the research team identified in this study focus on the problems associated with communications via network infrastructure.

The network infrastructure includes any number of radio sites depending on the size of the area to be covered. A site can act as either a base station or a repeater and can link any subscriber units as long as they are in the coverage area of the radio network. Figure B-1 depicts the operation of a single-site conventional repeater system. It operates using two channels, one for subscriber unit "talk-back" transmissions and one for repeater "talk-out" transmissions.

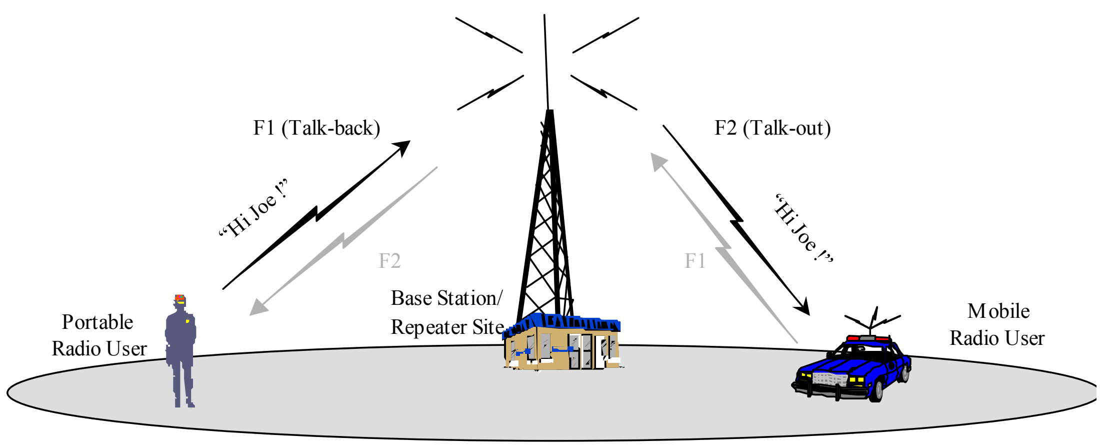

Figure B-1
Single-Site System Configuration[2]

To establish communications with the system infrastructure, the user depresses the push-to-talk button on his or her radio and "talks back" to the radio site. The radio site or a repeater receives the signal and rebroadcasts the signal or "talks out" to other field users. Talk back

[2] The PSWN Program. http://www.pswn.gov/library/docs/cvtcomp_repfinl.doc.

refers to the ability of field users using portable or mobile radios to talk back to the network infrastructure. Talk-out refers to repeater signals that can be received in the field by subscriber units. Often, talk-out signals have greater range because the fixed infrastructure equipment is not limited in size and thus is capable of operating at a much higher transmit power. The subscriber unit is much more limited in its ability to operate with high power because it is a mobile device that is limited in size, necessitating smaller batteries. Portable subscriber units are further limited because they are carried around by users and located very close to the body of the user when communicating to the infrastructure. For safety reasons, the operational power must be kept within a limited range. Typically, a base station can operate at several hundred watts of power while a portable transmitter is limited to 3–5 watts of power. The result of this power imbalance is that a user in the field could be in an area with talk-out coverage, but no talk-back coverage. In this case, the user would be able to hear the dispatcher (or some other message sent by the network infrastructure) but the dispatcher would be unable to hear the user.

This imbalance is of critical concern for wireless coverage within a building. Frequently, the signal strength is strong enough to penetrate a building from the repeater but the subscriber unit does not have enough power to communicate back. To provide proper coverage within a building, the coverage required from the subscriber unit back, or the talk back, is generally the problem that must be resolved. One way that network planners work around this problem is to deploy receive-only radio stations throughout a market. In this case, the lower power subscriber unit can transmit to a much closer receive-only station, which mitigates the lack of high power with less loss of signal through the air over a shorter distance.

RF or electromagnetic radiation signals are used to create links between subscriber units and the network infrastructure radio sites. As the radio signal travels between a tower and a subscriber unit, it loses strength as the signal is attenuated by the atmosphere. Attenuation of an RF signal is analogous to friction that occurs as an object moves over the ground. Attenuation of a signal is caused by many factors and is different for different parts of the radio spectrum. In general, attenuation occurs due to the following factors:

- **Reflection**—occurs when RF energy reflects off another medium. The medium could be something soft like two layers of the atmosphere with different densities, or something hard such as a building made of concrete. Sometimes RF energy reflects off an object in many different directions. This special case of reflection is called scattering.

- **Refraction**—happens when RF energy hits another object that could be another layer of the atmosphere or a building as discussed above, but rather than the signal reflecting off of the object, some of the energy penetrates the object at a lower power level and generally changes direction.

- **Absorption**—is the phenomenon of RF energy actually being absorbed by an object or medium in its path.

- **Diffraction**—can occur when an RF signal encounters a hard object such as a building. Some of the energy of the signal will hit the building and essentially bend around it. When this occurs it is called diffraction. Diffraction can mitigate the effect of absorption, reflection, and refraction in some cases for some locations by bending the beam to the user.

Each of the above factors have many different aspects associated with them depending on the frequency, the path of the RF energy, and the objects that the RF signal encounters along its path. In reference to in-building wireless communications, these factors are primarily important because they tend to reduce the power level of RF signals as they pass through building materials. The strength or power level of RF signals is typically measured in decibels. A decibel (dB) "is primarily used as a measure of the (power) gain and (insertion) loss of RF components."[3] It is a logarithmic measure that allows losses and gains to be added to each other as opposed to the more tedious methods required when working with watts. It should be noted that when working with RF systems, because very large and small numbers are used, use of decibel units tends to simplify calculations that would otherwise be unnecessarily complex. As an example of how decibels can be used to represent losses and gains in the RF environment, an increase in the power level of a signal from 10 watts to 20 watts (or doubling) could be said to have increased by 3 dB. For practical use, engineers use the unit of dBm to express power levels in the RF environment. The ordinances identified in this report also use dBm to describe the required minimal signal strength. The use of dBm is an extension of dB, but is normalized to one milliwatt. Table B-1 illustrates common power levels of interest and those referenced in the ordinances. For example, –107 dBm and –95 dBm are the receiver sensitivity power levels of some radios and the minimal standards listed in the ordinances. Five watts is the transmit power of a typical portable radio.

Table B-1
Power Levels in Equivalent Watts and dBm

Power in dBm	Power in Watts
-107 dBm	2×10^{-11} mW
-95 dBm	3.16×10^{-10} mW
-10 dBm	0.1 mW
0 dBm	1 mW (0.001 watts)
30 dBm	1 watt
37 dBm	5 watts
50 dBm	100 watts

The signal-to-noise ratio (SNR) is "the ratio of the amplitude of the desired signal to the amplitude of noise signals at a given point" and is usually expressed in dB.[4] For a radio to properly receive a RF signal and interpret the intended message, a minimum SNR must be met. Because a radio signal must pass through the atmosphere and, in some cases, solid objects such as buildings, a radio network is designed such that there is "extra" signal or margin to account for the effects of attenuation. Many forms of attenuation can be predicted, such as the loss of RF

[3] Weisman, Carl J. *The Essential Guide to RF and Wireless*, Prentice-Hall, Inc., 2000, p. 198.
[4] Institute for Telecommunications Sciences. http://www.its.bldrdoc.gov/fs-1037/dir-033/_4849.htm.

energy through the atmosphere, but other forms of attenuation are far more unpredictable, such as attenuation through buildings. When designing the coverage of a network, a specified extra margin is engineered into the network depending on how much coverage is desired and how much extra allowance there will be to accommodate the attenuation that occurs when radio signals penetrate buildings.

B.3 In-Building Coverage Overview

Public safety personnel often attempt to communicate via their portable subscriber units inside buildings. These communications, like any others using the network infrastructure, can only be successful if the radio signals from the portable radio can be received by at least one radio site and vice versa. In addition, the radio signals must be received at a high enough power level to meet the minimum SNR so that the message can be understood or decoded. The minimum power level required in the ordinances is either –95 or –107 dBm. Wireless communications inside buildings are affected by several primary factors, which are discussed in more detail in the following sections—

- Distance of the building from the nearest radio site
- Orientation of the user in the building in relation to the nearest radio site
- Spectrum band used by the network
- Type and density of the material used to construct the building.

B.3.1 Distance of the Building From the Nearest Radio Site

As the signal travels between the radio site and subscriber unit, it is attenuated. RF signals lose energy simply penetrating the atmosphere because some of the signal is reflected, refracted, and absorbed by molecules in the air. Other factors can cause additional attenuation, such as raindrops, clouds, ground vegetation, hills, and manmade objects like buildings. Additionally, as the signal travels from the transmitter, it spreads over an increasing area and is dispersed. This dispersion reduces the strength of the signal available at any specific location. The loss of signal over free space is equivalent to 6 dB each time the distance traveled doubles. That means that a user who is 12 miles away from a radio transmitter will receive a signal 12 dB weaker than a user who is only 3 miles away. Clearly, distance is a major factor in the strength of a RF signal. In terms of in-building coverage, this means that a user who is in a building 3 miles away has 12 dB more signal to penetrate the walls than does a user who is in a building 12 miles away. It is important to note that the 12 dB stronger signal of the closer site is equivalent to four times the power received from the site further away. As illustrated in Figure B-2, the signal strength available decreases dramatically as the distance from the transmitter grows. A building located closer to the radio site will have fewer problems with in-building coverage.

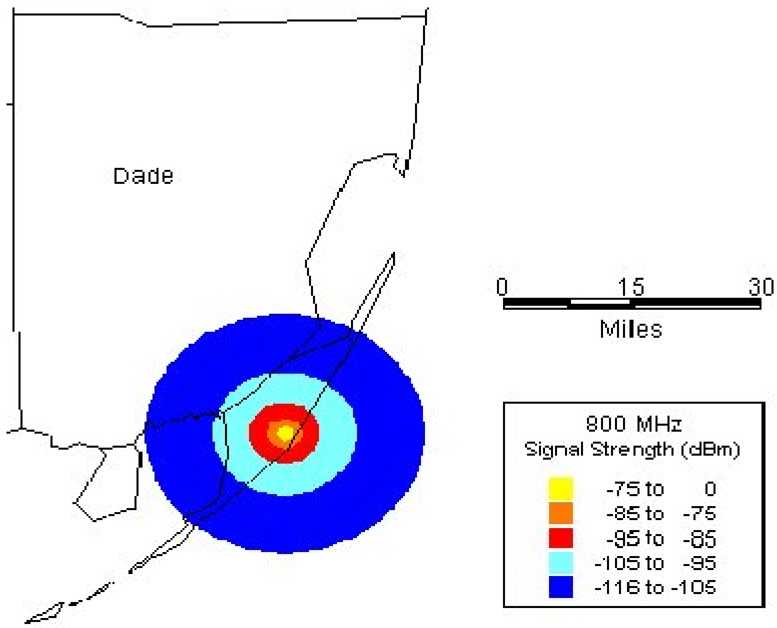

Figure B-2
RF Coverage Plot for a Typical 800 Megahertz System

B.3.2 Orientation of the User in the Building in Relation to the Nearest Radio Site

The user's location within a building also has a very strong impact on the amount of additional attenuation that will occur. If, for example, a user is located toward the top of a building, there is a much greater likelihood that that the signal will not be blocked by other buildings in the local area or other hard sources of blockage such as hills and vegetation. On the other hand, if a user is located on the ground floor of a building in an urban location, the RF signal may need to "pass though" several buildings, mountains, or trees even before it gets to the building in which the user is located. An even more extreme case occurs when the user is located in an underground parking garage or a below grade floor. Additional attenuation occurs in penetrating several floors of the building and perhaps even part of the Earth itself.

B.3.3 Spectrum Band Used by the Network

As the radio signal travels through the air, it is reflected, refracted, diffracted, and/or absorbed as indicated earlier in this document. The frequency of the signal that is being transmitted also has a significant impact on effects of the various forms of attenuation. What is most relevant about frequency is the wavelength. As frequency increases, wavelength decreases proportionally. As an example, the wavelength of a 30 megahertz (MHz) signal is 10 meters. On the other hand, an 800 MHz signal has a wavelength of only 37.5 centimeters (cm). Table B-2 lists the wavelength of the RF spectrum bands of interest in this study.

Table B-2
Wavelengths for RF Spectrum Bands of Interest

Description	Frequency Range	Wavelength	Attenuation Impact
Ultra High Frequency	300 MHz–3 GHz	1 m–10 cm	↑
Very High Frequency	30–300 MHz	10–1 m	
High Frequency	3–30 MHz	100–10 m	

Specifically, very high frequency (VHF) signals have a much longer wavelength than those in the ultra high frequency (UHF) band. The impact of this difference is that when a large wavelength signal encounters an object like a building wall, it is large enough that the wall is proportionally small and the building is opaque to the signal, and thus most of it passes through. A high UHF frequency with the small wavelength of 30 cm sees a building wall as a proportionally large obstruction and thus it is attenuated to a greater degree. Generally speaking, the higher the frequency, the smaller the wavelength, and the more attenuation a signal suffers when penetrating proportionally large objects.

Please note, for the purpose of this report, RF signals of approximately 800 MHz will be referred to as UHF signals. Although 800 MHz RF signals are part of the UHF band, they are sometimes referred to in other reports and documents as if they were part of a separate band. For this study and report, it is not necessary or desirable to make such distinctions.

B.3.4 Type and Density of Material Used to Construct the Building

A building's composition affects the propagation of radio signals. Radio signals entering a building are partially absorbed and partially reflected; the extent depends on the type of building materials encountered. For example, high-rise structures are typically composed of reinforced concrete and steel, which have a greater effect on RF signals when compared with the wood used in smaller buildings. Dense materials, particularly materials that are metallic, typically cause the greatest amount of attenuation. Concrete is another material that exhibits a high level of attenuation. Furthermore, materials used in windows, such as lead, may also reflect radio signals, which causes additional attenuation of the radio signal. In practice, the radio signal reaching a user within a building must pass thorough many different materials depending on the location of the user within the building. A representation of the typical attenuation values associated with various materials is shown in Table B-3.

Table B-3
UHF (300 MHz–3 Gigahertz) Building Materials Loss Measurements[5]

Material	Attenuation (dB)
Ceiling duct	1–8
Small metal pole (6” in diameter)	3
Foil Insulation	3.9
Metal stairs	5
Concrete wall	8–15
Loss from one floor	13–33
Loss from two floors	18–50
Aluminum siding	20.4

B.4 In-Building Coverage Scenario

A typical portable radio transmits at 5 watts (37 dBm). If the user of a portable radio attempts to talk back to a radio site that is 10 miles away from the building in which he is located, and he is transmitting from the basement of that building, the communication may not be successful. Given a typical transmit power, and the various losses discussed above, Table B-4 provides a link budget that illustrates a typical in-building scenario. For comparison, a link budget is provided for a street-level, outside talk-back scenario for a similar location.

Table B-4
A Talk-Back Link Budget for a Typical In-Building Scenario

Parameter	In-Building Talk-Back Power Level (dBm)	Street Talk-Back Power Level (dBm)
Portable transmit power	**37**	**37**
Human body loss	-4	-4
Antenna gain	-2.2	-2.2
Effective radiated power of the portable radio	**30.8**	**30.8**
Two floors	-30	N/A
Concrete wall	-10	N/A
Aluminum Siding	-20.4	N/A
Path loss (10 miles)	-100	-100
Receive Power (@ radio site)	**-129.6**	**-69.2**

As can be seen from the basic link budget, the RF signal sent from the basement of the building is dramatically degraded compared with the street-level communications. Most land mobile radio repeaters and base stations have receiver sensitivity levels much lower than –129 dBm, and therefore, would not be able to successfully receive the signal sent from the basement of the building. The minimum requirements used in the identified ordinances are –95 dBm and –107 dBm. This link budget illustrates why wireless networks that are able to provide adequate street coverage often encounter difficulties operating inside buildings.

[5] *See generally,* Rappaport, Theodore S., *Wireless Communications Principles and Practice*, Prentice-Hall, Inc., 1996.

B.5 In-Building Coverage Solutions

There are two methods, active and passive, for improving in-building radio communications. An active method, which requires a power source, receives, retransmits, and amplifies the radio signal. A passive device does not require a power source and simply retransmits the RF signal without any amplification.

The following solutions can be used to improve in-building coverage either as standalone solutions or together in various combinations as components of a system:

- Radiating cable
- Passive antennas
- Bi-directional amplifier (BDA) systems
- Distributed antenna systems.

B.5.1 Passive Methods

Radiating Cable. Radiating cable or "leaky coax" is a passive device that can be used to improve wireless communications coverage in confined areas. The cable functions like a continuous antenna. It is outfitted with controlled slots in the outer conductor that allow RF signals to be coupled between the coax cable and its surrounding environment uniformly along the entire length of cable. Furthermore, radiating cable helps to evenly distribute the power throughout a coverage area. Radiating cable is a viable option for communicating in buildings where the potential for RF blockage of point-source antennas due to obstructions is high and where multiple services such as public safety and emergency communications, cellular, personal communications services, and paging communications are essential.[6]

Passive Antennas. Passive antennas can also be installed externally and internally to a building to improve coverage. In order for this solution to be effective, very strong signals from the donor site are necessary, along with short coaxial cable runs when connecting the antennas.[7] Also, the highest practical gain antennas should be used.

B.5.2 Active Methods

BDA Systems. BDAs increase the signal level for talk-back and talk-out coverage and can improve coverage inside a building that has spotty or no radio coverage. As depicted in Figure B-3, a BDA system is composed an amplifier inside the building and an internal and external antenna network. The external antenna, usually located on the roof of the building needing coverage, receives the signal from the radio site. The BDA then receives and amplifies the signal from the antenna and transmits it through the coverage antenna. The internal antenna network radiates a signal into the building for portable radio reception and receives the signal from portable subscriber units being used in the building, and then transmits that signal back to the BDA. Finally, the BDA transmits the signal to the external antenna, which radiates a signal back to the radio site, completing the transmission.

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[6] Andrew Corporation. www.andrew.com.
[7] Stoll, George R., *Bi-Directional Amplifiers—Enhancing Radio Coverage in Shadowed Areas and Inside Buildings.* February 11, 2002 (*Stoll*), Slide 5.

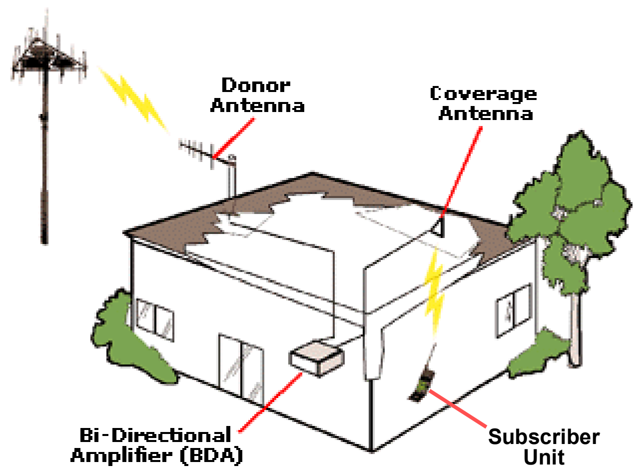

Figure B-3
BDA System[8]

A BDA operates over a range of frequencies in a pass band and at lower power levels when compared with a repeater, and will not work on a simplex system. There are two types of Federal Communications Commission (FCC) accepted BDAs. Class A boosters amplify discrete, narrowband frequencies, while Class B boosters amplify a pass band of broadband frequencies. Typical donor antennas used in implementing in-building systems include Yagi antennas, corner reflectors, panels, and parabolics, while conventional antennas or radiating cable are used as coverage antennas inside the building.[9]

Proper system design and placement of BDAs are critical elements when planning in-building systems. A BDA will amplify signals other than the signals desired by the application. If a system design flaw causes interference to other users, the BDA system should be adjusted. However, if the interference problem persists, by FCC ruling, the BDA system must be disconnected. An FCC license is not required to operate a BDA as long as the effective radiated power is less than 5 watts, and the amplified frequency is retransmitted only on the exact frequency of the originating base, fixed, mobile, or portable device(s). When coverage is required inside very large buildings, BDAs may not meet the coverage requirements and in those cases, a repeater may be appropriate. The overall system design would be very similar.

Distributed Antennas. For larger buildings, a distributed antenna system can be used along with a repeater or BDA to radiate the signal throughout the building. As illustrated in Figure B-4, it consists of small antennas that are strategically located throughout a building. A distributed antenna system allows the desired signal to be captured over the air from an external antenna, typically located on the roof, and then retransmitted through a network of small low-power antennas inside the building. These small antennas are located strategically throughout the building where the coverage is limited. The antennas are usually small and inexpensive, and

[8] Allen Telecom Inc. http://www.antenna.com/repeaters/trunkingkit.html.
[9] *See* Stoll, Slide 8.

the factor limiting their deployment in a building is the cable required to connect them all back to the main antenna on the roof. Fiber optic cables can carry the communications information over much greater distances than coaxial cable. For very large buildings, it may be necessary to use fiber optic cables to distribute signals rather than coaxial cables.

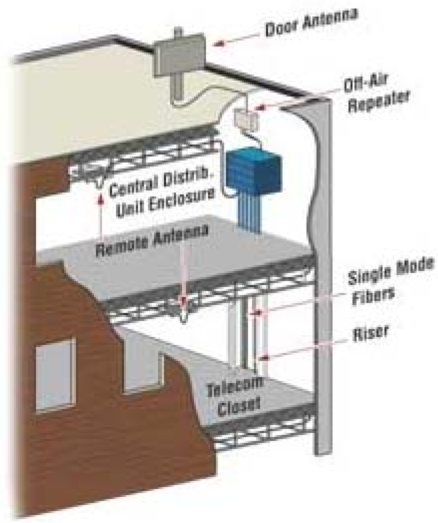

Figure B-4
Distributed Antenna System[10]

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[10] http://www.andrew.com/ACCESS/1001/articles/inbldwireless.asp

APPENDIX C—FINANCIAL ISSUES

APPENDIX C—FINANCIAL ISSUES

The Public Safety In-Building Ordinances and Their Benefits to Interoperability Report assesses the ability of laws, regulations, and ordinances to effect the development of in-building wireless systems that mitigate or resolve the problem of public safety in-building wireless communications. One aspect of assessing the impact of the ordinances is to establish general estimates of the cost of the various solutions that might be required by the ordinances. The purpose of this appendix is to review the overall costs related to implementing wireless communications systems inside buildings.

C.1 Approach

The approach for developing this financial analysis was to use practical examples and current market information to estimate the cost to procure and install communication systems that would meet the requirements of the ordinances. The Public Safety Wireless Network (PSWN) Program research team developed cost estimates for communications systems to operate in several different types of buildings. These estimates were based on current costs for the types of systems that might be required for the buildings. The research team used a bottom-up approach and information gathered from system manufacturers and installers to develop these estimates.

C.2 Types of Buildings Requiring In-Building Systems for Public Safety

The ordinances identified in this study apply to almost any type of building other than single-family homes and other small residential structures. Therefore, a wide variety of public and private structures may require installation of in-building systems to enhance the coverage of public safety wireless networks, such as—

- Shopping malls, casinos, and convention centers
- Airports, stadiums, and museums
- Office buildings, factories, and utility plants
- Hospitals and hotels
- Apartment complexes and other large residential buildings
- Government centers, courthouses, and detention facilities.

Each category of building includes a wide variety of structures that may require very different types of in-building solutions. For example, while the size and layout of two office buildings may be similar, the two may use very different building materials that impede radio signals differently. While one building may require only a relatively simple and low-cost solution to provide the necessary coverage, another may require a more complex and expensive system to overcome more complicated coverage issues. Therefore, to understand the costs related to in-building solutions, it is necessary to understand the factors affecting the complexity of in-building solutions.

C.3 Factors Affecting the Cost of In-Building Solutions

Size and shape, floor plan, and building materials are just a few of the factors that can affect the cost of an in-building system. The one characteristic that will provide an "order of magnitude" type estimate and is used by most industry professionals is the area of habitable space. Generally, the area requiring coverage will determine the type of solution that would be appropriate for the building and will help determine the complexity and cost of the solution. However, in addition to size, many other factors affect the cost of the in-building solution. The following are issues that are not related to the size of the building but that affect the cost of in-building solutions:

- **Type of Building.** The type of building is determined by the building material and floor plan complexity. Appendix B provided a discussion of how building materials can impede radio signals. If the building materials greatly impede radio signals, the in-building solution will be more complex to enable access in the various rooms. Floor plans are another characteristic defining different buildings. For example, a typical airport terminal may include 1 million square feet of space and be constructed with concrete and steel. The layout of the terminal space provides several large open spaces with relatively few walls. On the other hand, a 10-floor office building might provide a similar amount of office space and also be made of concrete and steel, but the office building will likely include many more walls and other barriers to the radio signal. Therefore, although the airport terminal and office building consist of the same area and the same building materials, the office space may require a much more complex solution to provide coverage throughout the building.

- **Timing of the Design and Installation of the Solution.** Most in-building solutions are designed and installed after the building is constructed. However, if the in-building solution is designed before the building is constructed, the overall cost of the system may be reduced. A primary cost component for any in-building system is the labor cost related to designing and installing the system. According to several installers, the real cost of these services is typically half the total cost of the system. Any reduction in the time required to perform these tasks can have a significant impact on the overall solution cost. If the solution is designed before the building is built, changes can be made to the building design that will ease the installation of the system. The fiber optic or coaxial cable distribution network installation can be simplified if physical access is provided while the building is still under construction. This could save a great deal of installation time for the in-building solution. Of course, if an in-building ordinance is enforced retroactively on building owners, they will have no option but to design and install in-building solutions after construction.

- **Severity of the In-Building Problem.** Not every building requiring wireless access improvements will need enhancements throughout the entire building. For example, an office building like the Sears Tower in Chicago has 4.4 million square feet of office space. If this building required an in-building solution for every floor, it would be a complex and expensive solution, probably costing millions of dollars. However, in many cases, parts of buildings have adequate coverage while others do not. The in-building solution will be tailored to meet the specific needs of the relevant building and the cost will likely be lower. A building like the Sears Tower may require enhancements for the parking garage and the lower floors, while the upper levels have access to the public safety network because the radio frequency (RF) signal path to the radio site is less obstructed by other buildings. In that case, the solution would only be required for 100,000 square feet of area rather than millions of square feet and would be much less expensive. For this reason, the cost of the solution for each building depends on the specific circumstances of that building.

- **Commercial Wireless Solutions.** Some solutions could be installed and become part of a larger system to provide in-building access to commercial wireless services. This might be an important factor when estimating the cost of in-building solutions for casinos, stadiums, and other large public venues where commercial wireless services are desirable but otherwise obstructed. In those situations, the overall cost of designing and installing an in-building solution for a public safety communications system can be shared with the commercial systems. For any given building where one or more commercial systems might be required to supplement the public safety system; the overall requirements might be very similar and could be more efficiently designed and installed at the same time by the same technicians. This could lower the cost for the public safety communications system.

C.4 Cost Estimates for Typical In-Building Solutions

In-building solutions have costs based on the design and installation labor, antennas, amplifiers, repeaters, and the distribution networks. As explained above, the type of system required for a building is based on many factors. The goal of this appendix is to provide an analysis of the financial impacts of in-building ordinances. As was demonstrated, each situation, building, and required solution is unique, and providing generalized cost estimates for in-building solutions could be misleading. However, based on market research, specific costs can be provided for specific cases. Each building and situation varies, and requires a tailored in-building solution. ; The examples and information provided below describe only "order of magnitude" data and should not be used to guide cost estimation for any particular building.

For example, a 45,000 square foot floor of a building could be covered with 300 feet of radiating coaxial cable installed above a dropped ceiling. The cable would be installed as one continuous length, center fed via a power divider. In this particular example, 1 linear foot of cable provides 150 square feet of coverage. As detailed in the Table C-1, material cost for this type of installation is approximately $4,020, while labor cost is approximately $1,210 for a total cost of $5,230.[11] These estimates use typical values for materials and labor costs. Cost will vary depending on the manufacturer of the materials and location of installation.

[11]Morgan, Mike, *Radiating Cables and the Three C's: Containment, Coverage, Cost*, March 1994. http://rf.rfglobalnet.com/library/ApplicationNotes/files/2/radcables.htm

Table C-1
Radiating Cable System Cost for a 45,000 Square Foot Building Floor

Number of Components	Material	Cost	Total Cost
Materials			
300 feet	Radiating Cable	$4.00/foot	$3,200
	Miscellaneous Components (i.e. cable ties, connectors)		$820
		Total Materials Cost	**$4,020**
Installation			
		Total Labor Cost	**$1,210**
		TOTAL JOB COST	**$5,230**

As another example, a bi-directional amplifier (BDA) system could be installed in a 200,000 square foot area, such as a warehouse, with various sections partitioned from one another. To provide wireless communications coverage for public safety personnel, a system for this building would cost approximately $33,000 as illustrated in Table C-2. These cost estimates are based on averages obtained from in-building wireless vendors. As noted, all buildings are unique, and the cost of a solution depends largely on the size, shape, and floor plan of the building, along with the materials used in construction and its proximity to a radio site.

Table C-2
BDA System Cost for a 200,000 Square Foot Warehouse

Number of Components	Material	Cost	Total Cost
Materials			
5	BDA	$4,000 each	$20,000
1,500 feet	Coaxial Cable	$1.00/foot	$1,500
	Miscellaneous Components (i.e. cable ties, connectors)		$5,000
		Total Materials Cost	**$26,500**
Installation			
		Total Labor Cost	**$6,625**
		TOTAL JOB COST	**$33,125**

In addition, according to one vendor in the wireless communications industry, "it would cost approximately $19,000 to cover a 20,000 square foot, one-floor structure, while covering a five-floor, 400,000 square foot structure would cost approximately $65,000." Specific cost breakdowns have not been provided in these instances. Clearly, the highest cost in-building solutions are those required for very large buildings in urban environments. The cost of these solutions may be of greatest interest. They are also the most difficult to predict. The examples provided in this section were quite basic and are useful for understanding the type of costs related to in-building solutions for relatively small buildings. Solutions for large buildings in urban environments are much more complex and costly. As discussed earlier, there are a wide variety of unpredictable issues that affect the complexity and cost of such solutions.

The uncertainty associated with urban area costs for in-building solutions is a major concern related to current and proposed ordinances. The recent report commissioned by the New York City Fire Department, entitled "Increasing FDNY's Preparedness,"[12] dealt with this issue. The report makes several recommendations regarding its finding that in-building communications during the emergency response at the World Trade Center was poor. To prevent such problems in the future, the report estimates that "[i]t would cost $150 million to $250 million to install [the necessary] repeater systems."[13] Furthermore, the cost of outfitting high-rise buildings taller than seven stories in New York City with in-building solutions was estimated at $0.30 to $0.60 per square foot. According to the estimate, the cost to install an in-building system in one major high-rise is between $1 million and $2 million. This estimate assumes that the entire building has inadequate in-building coverage. However, this will not always be the case, and the cost could be substantially lower. For example, if the high-rise structure is located near a network radio site, in-building communications may not be a problem at all. The requirement for building owners to pay for in-building systems will not be distributed equitably. In addition, for those required to make such improvements, the cost could be quite high.

C.5 Relative Costs of In-Building Solutions

Despite the numerous factors affecting in-building solutions, the research team was able to make some generalized estimates. The type of solution applicable to buildings of various types and sizes can be predicted. For example, for a very large building, like a modern casino, a passive system would not be acceptable. Assuming the entire casino complex required improved access to the public safety network, a passive network probably could not carry the radio signal from the various rooms out to the rooftop donor antenna without amplification. Also, for a very large casino complex, an active amplification system would need to distribute the radio signal to and from numerous antennas spread throughout the complex. When the length of the distribution link exceeds 100 meters, the effectiveness of coaxial cable as a distribution medium decreases significantly. Therefore, for a large casino complex, it would likely be necessary to install a repeater or BDA system using a fiber optic cable distribution network. Using that analysis for other types of buildings, the research team created Table C-3 to provide a breakdown of the types of solutions, their typical applications, and their relative costs.

[12] "Increasing FDNY's Preparedness," August 19, 2002. This report was prepared for the New York City Fire Department following the September 11, 2001, attack on the World Trade Center. The complete report is available at http://www.nyc.gov/html/fdny/html/mck_report/toc.html
[13] *Id.,* at p. 13.

Table C-3
Relative Costs of In-Building Solutions

	Type of Solution	Typical Coverage Area	Type of Building	
Passive Systems	Radiating cable system	Up to 50,000 square feet	• Small office Building • Warehouse • Parking garage • Courthouse • School	Lowest Cost
	Passive antenna system			
Active Systems	BDA system using coaxial cable distribution	5,000–250,000 square feet	• Office building • Museum • Hospital • Shopping mall	
	BDA system using fiber optic cable distribution network	20,000–500,000 square feet	• Large factory • Airport • Stadium • Casino • Hotel	
	Repeater system using fiber optic cable distribution network	200,000+ square feet		Highest Cost

APPENDIX D—DEVELOPMENT, IMPLEMENTATION, AND BENEFITS OF IN-BUILDING ORDIANANCES

APPENDIX D—DEVELOPMENT, IMPLEMENTATION, AND BENEFITS OF IN-BUILDING ORDINANCES

The Public Safety *In-Building Ordinances and Their Benefits to Interoperability Report* assesses the ability of laws, regulations, and ordinances to effect the development of in-building wireless systems that mitigate or resolve the problem of public safety in-building wireless communications. As part of this study, the Public Safety Wireless Network (PSWN) Program research team identified existing and proposed ordinances, investigated the relevant technical and financial issues, and gathered a variety of information from interested public safety professionals. As part of this study, it is useful to examine the overall impact of the ordinances and to analyze relevant trends related to their implementation or effectiveness. The purpose of this appendix is to review the overall trends, impacts, and other related findings that have been identified.

D.1 Approach

Appendix D focuses on the perceptions and impacts of ordinances in the seven localities listed in Section D.2. The assessment provided in this appendix is based on data obtained from surveys and interviews for each locality and a comparison of in-building ordinances among these localities. The data was collected in June, July, and August 2002, and most of the ordinances selected have been in place for at least 2 years. This study of the selected in-building ordinances' characteristics and their impacts includes an analysis of systems with in-building solutions and additional system-related information.

The research team reviewed 11 separate jurisdictions to determine system information, and compared the characteristics of each communication systems and the ordinances developed (and in seven of those jurisdictions, successfully adopted) to resolve communications issues encountered by public safety personnel. The research team inquired about the coverage concerns in each locality and the solutions that were adopted, both through application of wireless technology and through adoption of regulations, that would protect public safety users from outside interference. Many features of each system were examined to discern patterns and trends, and to determine the effectiveness that each system and the respective in-building ordinances. Although many of the systems and the in-building ordinances reviewed had similarities, some aspects of each were unique. The presence of these unique aspects underscores the need to tailor communications systems, and the in-building ordinances that regulate their use, to the specific coverage issues and problems that are of central concern to the public safety personnel that use those systems.

D.2 Issues Prompting the Establishment of In-Building Ordinances

Few municipalities have successfully enacted ordinances governing in-building public safety wireless communications capabilities in the United States. When detailed information was available from local officials, the information they provided indicated that those ordinances that were established were the result of specific needs on the part of public safety users. In large part, ordinances were established soon after a new system was implemented. Table D-1 provides the dates several localities implemented new systems and established in-building ordinances.

Table D-1
Summary of System Installation and In-Building Ordinance Codification Dates

Jurisdiction	System Installation Date	Year Ordinance Enacted
Boston, MA	1999	2000
Broward County, FL	1989	1999
Burbank, CA	1990	1991
Folsom, CA (Sacramento County)	1995	1999
Ontario, CA	1998	1999
Roseville, CA	1997	1999
Scottsdale, AZ	2001	2002

It is not always clear why each jurisdiction's public safety radio systems required specific in-building solutions. The reasons for improving in-building communication operations in each area varied, as did the treatment in the ordinances that were drafted to eliminate the problems that were occurring. Section D.3 of this appendix describes several issues related to the wireless networks.

There were several reasons localities established in-building communications ordinances. One of the primary reasons was the adoption of ultra high frequency (UHF) systems and the efforts to resolve problems that were detected after the new systems were implemented. All of the ordinances were passed because there was at least a perceived need to compel property owners to provide access, or at least not obstruct access, to the public safety wireless networks. For example, in Scottsdale, Arizona, the ordinance came about when crimes were committed in locations where system coverage was poor and public safety officials on site could not respond because of the lack of in-building wireless communications. In Broward County, Florida, the ordinance was proposed after a building that obstructed radio frequency (RF) signals was constructed next to a main radio site. The ordinance was seen as a means to address the issues with that building and others that might be built in the future. In both Boston, Massachusetts, and Ontario, California, the ordinances were drafted primarily as a response to repeated coverage problems experienced in high-rise buildings. In each case, public safety personnel were experiencing communications problems and began the process of establishing an ordinance to rectify those issues after being informed about existing in-building coverage issues or being prompted to take action following a major event.

D.3 Public Safety Wireless Networks Requiring In-Building Solutions

As noted above, this study identified seven jurisdictions that successfully implemented in-building ordinances. These jurisdictions typically established their ordinances after implementing a new public safety wireless network. Table D-2 provides information on the systems used in the relevant jurisdictions. The table shows that those jurisdictions that passed ordinances have a great deal in common in terms of the systems they implemented.

Table D-2
System Information

Jurisdiction	System Type	Mfr	Frequency Band	System Type	Encryption
Boston, MA	Conventional	Motorola	UHF (483–486 MHz)	Analog	No
Broward County, FL	Trunked	Motorola	UHF (800 MHz)	Analog	Yes
Burbank, CA	Conventional	Motorola	UHF (470–474 MHz)	Analog	Yes
Folsom, CA	Trunked	Motorola	UHF (800 MHz)	Analog	No
Ontario, CA	Trunked	Motorola	UHF (800 MHz)	Analog	Yes (partially)
Roseville, CA	Trunked	Motorola	UHF (800 MHz)	Analog	No
Scottsdale, AZ	Conventional	Motorola	VHF (153–155 MHz)	Analog	No
	Trunked	Motorola	UHF (800 MHz)	Digital	Yes

D.3.1 Common Manufacturer

As Table D-2 shows, the communications systems in all the jurisdictions identified that have passed in-building ordinances have a common manufacturer, Motorola. There is no clear reason for this. However, it may simply be because Motorola has built the majority of the local governments' public safety wireless networks. According to the data gathered through the PSWN Program's *LMR Equipment and Infrastructure Survey*, approximately 68 percent of local respondents use Motorola systems. Therefore, any locality that passes an ordinance is likely to be using a Motorola system.

D.3.2 Common Spectrum Band

The majority of the jurisdictions that adopted ordinances did so to specifically support new systems that operate in the UHF band. However, one of the jurisdictions with an in-building communications ordinance has a system that uses the UHF band, and another system that operates in the very high frequency (VHF) band. Although the ordinance applies to both the UHF and the VHF systems, the ordinance was not established until after the UHF system was implemented. Therefore, even in the one case where an ordinance applies to a non-UHF system, it appears that the ordinance was primarily needed to improve in-building communications operating in the UHF band.

The link between the establishment of ordinances and the implementation of UHF systems is significant. Prior research has demonstrated that approximately 78 percent of localities operate in the VHF spectrum band, according to the PSWN Program's *LMR Equipment and Infrastructure Survey,* which was conducted in the late 1990s. Since that time, many of those localities may have migrated their wireless networks to the UHF band. Even if there has been a significant transition, it remains likely that a majority of localities are still using VHF channels. Given that most localities are using the VHF band, yet all of the jurisdictions with ordinances use the UHF band, it could be inferred that UHF wireless networks are prone to in-building communications problems.

D.3.3 Network Design Issues

In general, analysis of the timing of the ordinances and the type of systems installed could lead to the conclusion that many newer systems were not designed to meet the public safety requirements for in-building communications. Wireless networks operating in the UHF band are probably not inherently flawed because of the chosen spectrum band. However, because of the propagation characteristics of higher frequency radio signals, more radio towers and a more expensive network infrastructure is typically required. In-building coverage can be provided for almost any environment if enough radio sites are included in the network infrastructure. Due to cost and other issues, system designers sometimes must compromise between operational requirements and practical financial concerns. The result can be an "under-designed" system that is lower in cost but does not provide the coverage required by the user community, especially in-building coverage.

D.3.4 Including In-Building Solutions in the Estimate of the Wireless Network Cost

When the systems listed in Table D-2 were procured by public safety agencies, the agencies did not consider the cost of the in-building solutions as part of the overall system cost. It is unclear whether the public safety agencies knew that they were procuring networks that would not provide adequate in-building coverage. Representatives of several localities noted that they passed their ordinances after specific in-building problems were experienced. Therefore, it is likely that it was not until after the system was implemented that they knew that in-building communications would be a problem. One public safety professional stated that his organization was surprised by the lack of in-building coverage when using their new UHF (800 megahertz [MHz]) system as compared with their older system. In cases in which the localities did not know that they were installing an inadequate system, little could have been done during the procurement of the system to resolve the in-building problem before system implementation, and the additional cost of in-building solutions may have been unavoidable.

In cases in which public safety professionals procuring a system knew that they would not have adequate in-building coverage with the proposed network infrastructure, they could have included in-building solutions as part of their overall system development plan. This approach to wireless network development would have allowed a more informed approach to making network design decisions. For example, one proposed ordinance has been rejected by a city council because of the estimated cost of the needed in-building solutions. The council's decision to reject the ordinance may have been justified with regard to the burden that it would place on the property owners. Even where in-building solutions were adopted by a locality, sometimes the local governments still paid for some of the in-building solutions that were deployed. This is especially true when providing wireless communication coverage inside government buildings. The financial burden of the in-building solutions must be supported by the community either through direct government expenditures or unfunded mandates under in-building ordinances.

A lower cost communications network infrastructure could result in the need for costly in-building solutions. The reverse is typically true as well—with a more complex network infrastructure that includes more radio sites, the cost of the network goes up, but the need for in-building solutions decreases and the overall cost of those solutions to the community decreases as well. Table D-3 illustrates this relationship between the cost of the network infrastructure and the cost of the in-building solutions.

Table D-3
Financial Relationship Between Network Infrastructure and In-Building Solutions

Number of Radio Sites	Cost of the Network Infrastructure	Need for In-Building Solutions	Overall Cost of In-Building Solutions
↑	↑	↓	↓

Addressing this issue before procuring a system allows planners to make system design decisions based on the true overall cost of the alternatives. As can be seen, the design of a wireless network that requires in-building coverage should include an analysis of the cost of the infrastructure and the in-building solutions. The overall cost of in-building solutions appears to be obscured in part due to the use of ordinances. The use of ordinances by localities may allow public safety agencies to enhance their network coverage inside buildings without purchasing new equipment. In effect, the requirement on the part of property owners to install an in-building system is a tax to support the public safety wireless network. Viewed in that context, this cost is similar to any other cost associated with the procurement of a public safety wireless network. Requiring property owners to implement in-building solutions for public safety is like levying a one-time real estate tax to support any other part of the public safety wireless network. Like other parts of the system, the in-building solutions are paid for by the community through taxes and should be treated as such. Including the cost of the in-building solutions will allow for a more informed and accurate cost-benefit analysis and comparison of wireless networking design alternatives. A comprehensive analysis of this issue may not have been possible in the localities identified in this report because they were probably unaware that their new systems would not provide adequate in-building coverage.

This point is illustrated by the experience of public safety professionals in Washington, DC. They have been engaged in an effort to improve in-building coverage as well as the overall effectiveness of their wireless networks. As discussed above, their effort will result in new financial costs in addition to the initial system procurement. In 2001, the Fire and Emergency Medical Services Departments in Washington, DC, procured a UHF (800 MHz) digital network from Motorola at a cost of $5.3 million. There were immediate in-building communications problems, and Lt. Ray Sneed, President of the D.C. Firefighters Association, described the situation as "a ticking time bomb."[14] To resolve the issue, the city will spend $10 million to

[14] *The Washington Times*, Matthew Cella, June 22, 2002

double the number of radio sites, $4 million to install in-building systems, $3 million for subway communications improvements, and $7 million for design and engineering services. The original system was not designed to meet critical operational requirements of the DC firefighters, which resulted in the need for extensive system enhancements (i.e., in-building solutions). Even if the city used an ordinance to shift some of the financial burden of the in-building solutions to private property owners, a large investment would still be required on the part of the city government for subway tunnels and government buildings.

D.3.5 Trunked, Digital, and Encrypted Networks

Another significant finding is that there does not appear to be a correlation between enactment of ordinances and whether systems are trunked, digital, or encrypted. One might expect that systems that are digital or encrypted would be more prone to in-building communications problems and therefore the jurisdictions involved would be more likely to pass in-building ordinances. This circumstance would apparently be due to the limits of the error correcting and overhead bits associated with digital and encrypted wireless communications. One public safety representative surveyed for this report stated that his department's new system was encryption capable but did not work properly, and the organization subsequently decided to abandon efforts to encrypt their transmissions. It was not clear whether any of the problems they had with encryption were related to in-building coverage issues, and no conclusion regarding in-building communications can be drawn from that one case. In addition, localities with analog and digital, encrypted and unencrypted systems have passed ordinances. In the localities with existing ordinances, there does not appear to be a correlation with these characteristics, which leads to the conclusion that these characteristics do not appear to be prompting the need for in-building systems or the establishment of in-building ordinances.

D.4 Drafting In-Building Ordinances

Based on the information gathered from the public safety professionals involved in drafting in-building communications ordinances and on the contents of the ordinances themselves, there are common methods and language for drafting in-building ordinances. Several professionals surveyed by the research team stated that established in-building ordinances from other jurisdictions were used to draft regulations for their own localities. By reviewing the ordinances, it is clear that several ordinances use almost identical format, structure, and language. Some examples of the language most frequently found in the ordinances includes—

- All of the California jurisdictions include language in their in-building ordinances that approximates the following statement: "Except as otherwise provided, no person shall erect, construct, change the use of, or provide an addition to any building or structure or any part thereof, or the cause the same to be done which fails to support adequate radio coverage." This statement varies slightly in the City of Roseville ordinance and the draft ordinance for the City of Sacramento, as well as for Sacramento County, which further specifies that the building addition must be "of more than 20%" for the ordinance to apply. The cities of Grapevine, Texas, and Scottsdale, include such language as well. The opening sections of the ordinances also detail the communications system, including the operating frequencies, identify the public safety personnel to whom that the law applies, and typically also contain the statement that the ordinance's applicability "includes but is not limited to" the named personnel.

- Many of the ordinances detail minimum signal strength in either dBm or microvolts available in a certain percentage "of the area of each floor when transmitted from the system sight." These ordinances also mandate a minimum level for signal strength in dBm or microvolts received at the site when transmitted from a certain percentage area of each floor of the building, and specify the frequency range that must be supported. This is the case in six of the seven jurisdictions that have passed ordinances, as well as in the draft ordinances for both the cities of Sacramento and Grapevine.

- Many of the ordinances then detail the types of solutions that are permitted for improving communication coverage inside buildings. These recommended methods are described as "Amplification System(s) Allowed" in five of seven jurisdictions having passed such ordinances, and in two draft ordinances. Scottsdale has a similar section that refers to in-building solutions as "Enhanced Amplification Systems." Burbank's in-building communications ordinance contains typical language to describe use of typical amplification systems: "Buildings and structures which cannot support the required level of radio coverage shall be equipped with any of the following in order to achieve the required adequate radio coverage." All of the above jurisdictions allow use of radiating coaxial cable, or internal multiple antenna systems along with bi-directional amplification (BDA) systems.

- Another provision frequently found in the in-building communications ordinances reviewed by the research team was an exemption from coverage for buildings under a certain height or square footage area. This requirement varies from the Ontario ordinance's minimum requirement for amplification in buildings and structures more than 30 feet in height, to a minimum of 35 feet in Burbank and Scottsdale, to a minimum 5,000 square feet of area for buildings in Roseville, Sacramento County, and in the draft ordinance for the City of Sacramento. Other provisions frequently apply that make exemptions for wooden frame homes, single-family homes, and buildings constructed in specified residential areas. The Boston Fire Code's in-building radio specification is unique among existing ordinances because it does not provide any exemptions.

- With the exception of Broward County, all of the jurisdictions reviewed by the research team that have codified in-building communications ordinances require initial testing upon completion of installation and annual tests as evidence of ongoing compliance. In addition to system testing requirements, several jurisdictions have established qualification criteria in their respective ordinances. For example, in Boston, radio coverage testing personnel must be in possession of a current Federal Communications Commission (FCC) General Radiotelephone Operator License. Another approach, found in the ordinances of Roseville and Sacramento County, and in the draft ordinance for the City of Sacramento, allow either an FCC-licensed technician to conduct testing, or a person with certification issued by an accredited public safety organization. Authorized licensing organizations specifically included in these ordinances include the Association of Public-Safety Communications Officials-International, Inc. (APCO), the National Association of Business and Educational Radio (NABER), and the Personal Communications Industry Association (PCIA), which merged with NABER in 1994.

- The most frequently cited penalty in the ordinances—included in four of the seven jurisdictions that have passed ordinances—is for the building authority, fire department, or other designated agency to withhold or revoke the building owner's permit for actual use of the facilities. Boston's in-building radio specification states that "A certificate of occupancy may not be issued for any building or structure which fails to comply with this section." The Scottsdale, Burbank, and Ontario ordinances, and Grapevine's proposed ordinance, each contain a similar requirement.

- In addition to loss of occupancy permits, other penalties are attached in many of the ordinances studied. The City of Scottsdale has by far the strictest of the ordinances, mandating that "Any person, firm or corporation, whether as principal, owner, agent, tenant, or otherwise who violates disobeys, omits, or refuses to comply with, or who resists the enforcement of any of the provisions of this code is guilty of a class one misdemeanor, and upon conviction thereof may be punished by a fine not exceeding one thousand dollars ($1,000) or imprisonment for a term of not exceeding six (6) months or by both such fine and imprisonment, at the discretion of the city magistrate." Scottsdale and Broward County also leave the authority to enforce their ordinances open ended, and the penalties that may be levied may include imposition of additional remedies by other agencies having appropriate jurisdiction, to enforce compliance against violators.

According to research completed for this study, in-building wireless communications ordinances first became the topic of legislative initiatives to provide standard coverage levels for public safety wireless users in California cities. The first in-building communication ordinance was passed and codified in 1991 and is found in the Burbank, California, *City Building Code*. Other jurisdictions in California used this ordinance as a model, which became further refined as other municipalities defined terms and limited coverage to those structures that would be built after the ordinance took effect. A fire marshal who was working in Sacramento County after the passage of that jurisdiction's in-building communications ordinance later joined the Roseville Fire Department and used the Sacramento County ordinance almost verbatim in drafting Roseville's ordinance. Later, the City of Sacramento would attempt to increase coverage requirements in an initiative that goes beyond the standards of Sacramento County; however, the city's initiative has not been successful thus far.

Additional provisions of laws in other jurisdictions, such as penalties for non-compliance, testing procedures, and qualifications for personnel, would be drafted by administrators to address contended issues and provide remedies for regulations. Still others would mandate compliance generally, as in the case of Broward County and the proposed ordinance in Montgomery County, Maryland. In those documents, coverage levels, reliability, testing, and other specific provisions are not delineated. This lack of comprehensiveness may require those jurisdictions to supplement their ordinances in other sections of the respective county codes in order to define acceptable coverage guidelines for builders and developers, and the corresponding penalties for non-compliance.

The Boston in-building radio specification rule offers many departures from the majority of in-building communication ordinances passed in other jurisdictions. Boston allows building owners to implement wireless systems in lieu of installing the normal hard-wired telephone systems for firefighter communications. The hard-wired telephone systems were the fire code requirement for high-rise buildings but this rule, which amended Boston's Fire Code unilaterally, gave developers another option to consider. It is believed that this ordinance has been effective partly because developers have transitioned, of their own accord, from hard-wired communications to the use of BDAs. In addition, to achieve in-building coverage, the department previously allowed a dedicated channel repeater inside a building instead of a hard-wired telephone or BDA system. However, only one out of the department's four communications channels was operational with this type of solution, which was held to be ineffective. All four channels are operational inside buildings with a BDA system.

D.5 Challenges to Establishing In-Building Ordinances in the City Code

The 11 jurisdictions researched for this report were either successful in implementing the legislative process within their community, are unsuccessful because of a lack of political support and sense of urgency equated with providing better communications for public safety personnel, or are in various stages of drafting and adoption of in-building ordinances. Several jurisdictions attempted to pass ordinances creating obligations for building management, tenants, construction firms, and developers to adhere to standards for wireless communications coverage for public safety officials inside buildings. In some of those cases, they have met significant opposition from builders and real estate developers eager to contain construction costs.

In one case, the City of Roseville's Fire Department proposed an ordinance governing public safety wireless communications coverage inside buildings and met with the Roseville City Council and local Builders Industry Association (BIA). The council passed the measure without controversy. However, in other jurisdictions, the local BIA steadfastly opposed adopting such ordinances. The success of Roseville's ordinance may have hinged on the solicitation of support from that association early in the process. By enrolling the builders and developers as partners in the process of deciding how in-building public safety communications could be enhanced, the Roseville City Council had an ally that understood the issues and was willing to take responsibility for drafting and implementing those plans.

In Scottsdale, police officers were unable to communicate while three armed robberies occurred in the Fashion Square mall because the mall was built using a triple thickness of concrete. Officials recognized the need for the ordinance so in-building coverage would not continue to be an issue in future buildings. Public safety agencies, with support from city inspection services, were the major champions in ensuring the law was passed. The Scottsdale City Council voted affirmatively to pass the ordinance. In the City of Ontario, there was minimal resistance to the ordinance among the builder and developer community because public safety priorities may be better understood in light of catastrophic events like the Oklahoma City bombing. In Broward County, resistance from developers and construction companies due to cost surfaced but was not strong enough to prevent passage of the ordinance. Additionally, there were no challenges or active resistance to the in-building communications ordinance in Sacramento County.

Other jurisdictions that have attempted to pass such ordinances have failed. In those cases, political support for regulating new and existing wireless communication systems was insufficient to overcome resistance from builders and developers, who argued that implementing such measures would create greater expense and implementation difficulty than they could afford. During the economic downturn of the last 2 years, the building industry was among the hardest hit. The city and county representatives charged with passing proposed ordinances were persuaded to shelve legislation because of the threatened danger of increased unemployment and a lack of tenants to provide revenue in those jurisdictions.

For example, Grapevine has been trying to pass an ordinance since at least 2000. Champions of the legislation include public safety agencies and the City Manager's Office. However, the legislation has been tabled due to opposition from builders and developers because of the financial burden the ordinance might place on the building community. Much of the resistance to Grapevine's draft in-building communications regulation has been attributed to builders and developers successfully blocking the penalty provision of that proposed ordinance permitting a $2,000 per day fine to be levied against building owners for non-compliance. Montgomery County held a public hearing on its proposed Executive Regulations to "adopt and amend certain editions of the National Fire Codes regarding building construction and fire protection systems" in August of 2002. Fairfax County, Virginia, has only recently begun an initiative to draft language and remains undecided whether the proposed language will supplement the *Virginia State Building Code* or other section of the law that governs that jurisdiction.

In another area of the country, because of the influence of developers, a proposed ordinance was not fully supported by local elected officials, who had initially endorsed the measure to aid public safety personnel and other first responders. In addition, informal working arrangements exist that enhance coverage in many areas where ordinances are not passed. In one situation cited, as a condition of approval for commercial antenna tower sites, some developers have been willing to provide space on a tower or roof for a public safety transmitter, in exchange for expedited consideration of their zoning requests or a permit for approval of construction.

There is a perception among some officials within the public safety community that builders' and developers' interests are typically more focused on short-term costs. Under current market conditions, it would be difficult to mandate any measures that require greater investment than the commitments that they have already made. Conversely, if builders and developers install public safety in-building communications systems, they can also use the deployment of coverage solutions to their advantage. Builders and developers could tout enhanced protection of their properties through use of technologies to ensure better public safety radio coverage as a selling point to tenants.

D.6 Challenges to In-Building Communications Ordinances After Enactment

Typically, once a law concerning public safety wireless radio communications has been codified, there is very little resistance to complying with the law. As discussed above, resistance usually occurs during the legislative process. For example, in Boston, most building owners knew they must install either a hard-wired telephone or BDA system for the fire department, law enforcement, and emergency medical services, and did not challenge the law.

Additionally, a local shopping mall in Ontario (Ontario Mills) voluntarily retrofitted the facilities to meet the standards for communication coverage specified in the ordinance. The Ontario regulation would not have otherwise created any obligations for the retail stores to comply; however, because building owners understood the importance of public safety communications inside buildings, they made it possible to have enhanced coverage to protect these populous areas. In addition, developers were finding it far more cost efficient to ensure that they met Ontario communications coverage standards in advance, and that retrofitting buildings to achieve required signal strength levels later was much more expensive. In Scottsdale, there was minor resistance after the ordinance was passed. However, once building owners realized they would not receive certificates of occupancy without successfully meeting the wireless coverage standards, they were willing to cooperate.

The research team also has found no history of building owners, developers, or other interested parties challenging the in-building communications ordinances once they were enacted. Furthermore, public safety personnel interviewed in jurisdictions with ordinances were unaware of any legal challenges to the ordinances in their respective jurisdictions. The perception was that after an ordinance had been made law, builders and developers saw little chance to have it repealed, and that finding tenants for buildings where fire or building code provisions had been resisted might not easy.

D.7 Perceptions of Public Safety Professionals on In-Building Ordinances

During the data gathering effort for this study, public safety professionals in jurisdictions having in-building communications ordinances provided their impressions and perceptions of how well the ordinances have performed. Their comments illustrate how the ordinances are commonly implemented and how effective they have been in facilitating improved in-building communications. The following sections address several significant findings.

D.7.1 Installation of In-Building Systems

The most important effect of in-building communications ordinances is that in those localities where ordinances were established, they have successfully motivated building owners to install in-building solutions for public safety users. Some public safety representatives could not recall whether any systems had actually been installed, while many others knew of several that had been installed as a direct result of the ordinance. In the latter case, their impression was that the ordinance was instrumental in resolving the in-building communications problems among public safety personnel. In one jurisdiction where an ordinance has been tabled, the very threat of the ordinance has prompted some builders and developers to consider in-building systems during construction of new buildings in the area. In other jurisdictions, builders and communication providers that had previously caused interference to public safety communications have offered to install new solutions and technology to ensure compliance, and have not attempted to circumvent the process, cooperating fully.

D.7.2 Enforcement of In-Building Ordinances

While most of the ordinances have very specific guidelines for testing buildings to ensure that they meet the minimum technical standards, not all localities follow these testing and enforcement procedures. The ordinances often require very specific yearly tests, record keeping, and minimum technical standards. In some instances, public safety agencies do not have enough funding to test buildings every year in addition to buildings installing new systems. However, in those cases, the ordinance is enforced after a complaint has been made. After the complaint is verified, specific attention is given to the relevant building, and actions are taken to ensure that the owner complies with the ordinance.

D.7.3 Effect of In-Building Ordinances on Interoperability

None of the public safety professionals contacted for this study was aware of any direct or indirect impacts on interoperability related to in-building ordinances. Several of the knowledgeable professionals contacted had a great deal of experience in the area of improving interoperability between disparate public safety wireless networks. Some provided specific information about their recent efforts to migrate to shared systems, use common talk groups with other area public safety agencies, or establish mutual-aid channels for emergency joint operations. However, none of the past, current, or expected interoperability efforts were related to in-building ordinances.

D.7.4 Knowledge of In-Building Ordinances

The research team observed a wide discrepancy between jurisdictions regarding awareness among public safety personnel, as well as among the construction and development community, with respect to the enactment of regulations that govern the quality of in-building communications. In at least two of the locations that have codified ordinances, public safety personnel involved in communications for that jurisdiction's fire and police departments were not even aware that such a measure had been enacted. Furthermore, several representatives of fire and law enforcement agencies offered that because of the random location of ordinances in the fire code, building code, or other statutes, in-building communication requirements often had to be brought to the attention of builders and developers who were uniformed about their impact, the duties they imposed, or even of the ordinance's existence.

D.8 Interoperability Impact of In-Building Ordinances

As stated above, the perception of the public safety professionals contacted for this report was that interoperability had not been affected by the ordinances. Based on that information, in addition to an analysis of the types of systems used in the localities and the specific requirements set forth in the in-building ordinances gathered for this study, it can be concluded that in-building ordinances have little or no noticeable impact on interoperability between public safety wireless networks.

The impact of in-building ordinances on successful interoperability depends on the level of interoperability of the wireless networks, and the expertise and training of those agencies using them, that exists prior to development of standards for in-building coverage using in-building ordinances.

In-building ordinances only compel property owners to install in-building wireless solutions. The best case scenario for the wireless solution is that it allows public safety personnel to communicate seamlessly while traveling throughout the building in question. Essentially, the in-building solutions required by the identified ordinances only extend the coverage of existing systems to the inside of buildings. In terms of interoperability between wireless networks, the focus for joint operations is much larger than any particular building The main concern of public safety professionals involves interoperable communications for joint operations that can occur anywhere in the networks' coverage areas and is not limited to any particular building.

The primary measure of interoperability between disparate wireless networks is how well they interoperate throughout their coverage area, not inside any individual building. Because of the nature of how wireless networks are designed, the interoperability impact of any particular in-building solution would be minimal unless the overall systems were already interoperable. With that in mind, if two systems were interoperable either through a patch, switch, or other method that relies on the separate network infrastructures, an in-building solution could extend the interoperable communications to the inside of a building. This could be done if there were in-building ordinances that ensured that the subscriber units from each system maintained access to their network infrastructure while in the building. In that case, the interoperability link would work as usual and interoperability between the two systems would be extended to the inside of the building.

There is one jurisdiction that may be using their ordinance for this type of interoperability. In Scottsdale, fire and police personnel communicate on separate networks (i.e., VHF conventional analog and UHF trunked digital). Both networks are specified in their in-building ordinance, and minimum standards are set for each system to ensure in-building coverage for both. Additionally, the systems are interoperable through patching activated by a dispatcher. Fire and police, and other public safety personnel can communicate directly using their two separate systems, by switching to the appropriate channels or talk groups that are linked via patching. Also, because they have passed an ordinance that applies to both systems, the interoperability between the two systems should be maintained even when inside buildings. However, the public safety professionals contacted in Scottsdale did not provide any information supporting this finding and did not know of a situation where in-building interoperability, or interoperability in general, was positively impacted by their ordinance.

APPENDIX E—ACRONYMS

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APCO	Association of Public-Safety Communications Officials-International, Inc
BDA	Bi-directional Amplifier
BIA	Building Industry Association
dB	Decibel
FCC	Federal Communications Commission
MHz	Megahertz
NABER	National Association of Business and Educational Radio
PCIA	Personal Communications Industry Association
PSWN	Public Safety Wireless Network
RF	Radio Frequency
SNR	Signal-to-Noise Ratio
UHF	Ultra High Frequency
VHF	Very High Frequency