AC 2011-984: SYSTEMS ENGINEERING APPROACH TO FIRST RESPONDER INTEROPERABILITY

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Systems Engineering Approach to First Responder Interoperability

Abstract

The purpose of this paper is to investigate the technologies, policies and standards that are currently being developed to assist first responders in successfully managing major incidents. Using a systems engineering approach, the technology, policies, standards and procedures that are necessary in creating an effective system for disaster responses are evaluated and recommendations made. First responders need to work and coordinate with a variety of agencies that may not have similar communications equipment, policies and tools. First responders can find themselves unable to communicate with other agencies or unable to locate and apply resources when responding to a major incident or natural disaster. This can seriously hinder the ability to plan for and respond to major events. A successful system will aid in coordinating, tracking and managing resources. Specifically, an appropriate system can aid first responders in exchanging valuable information seamlessly and provide a factor of safety for the individual responder.

Introduction and Literature Review

From the first World Trade Center bombing in New York, to everyday interactions between local police, fire and emergency medical personnel, it has become increasingly clear that simple communications and coordination between responding agencies is difficult if not impossible given the severity of an event. Managing major incidents, tracking assets and resources is hindered by a lack of interoperability between the agencies[2]. Interoperability[3,4,5] encompasses the radio communications between the agencies as well as the coordination of responses and creating a command and control organization. Agencies each use their own particular set of communications equipment,

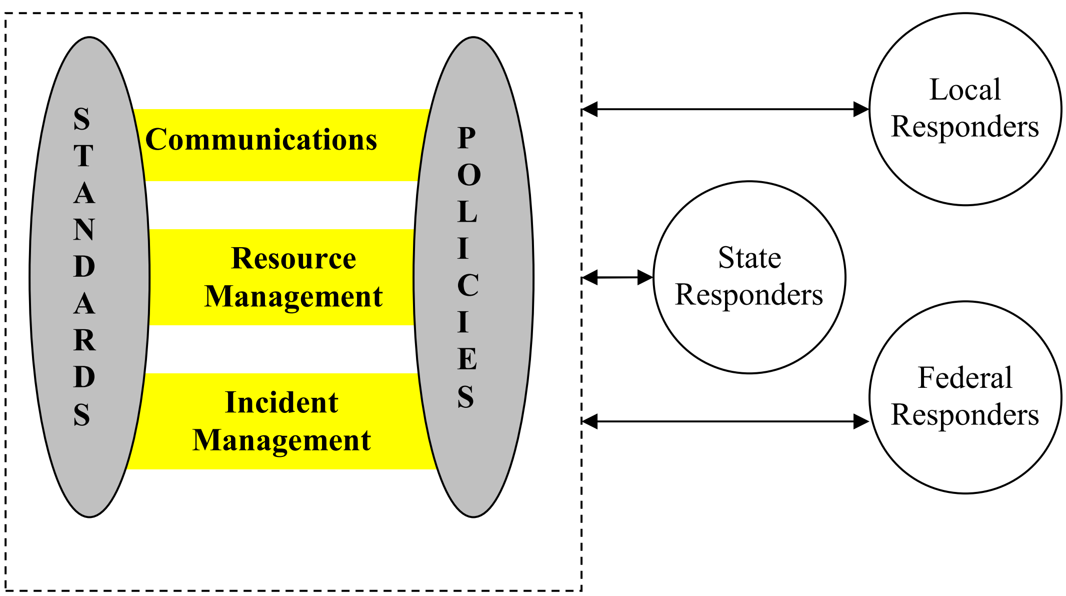

Figure 1 – System of Interest

operating in different portion of the radio spectrum and have specific protocols and methods of response.

The objective of this research is to use a systems engineering approach to investigate the issues within the first responder community. Technology can be a major part of the solution but by using this type of approach, a wider range of tools can be considered. Not only will technology solutions be discussed but applicable standards, plans and human factors will be part of the solution. The Department of Homeland Security (DHS) has developed a suite of documentation and proposals that aid the first responder community with funding and highlight some of the technology and standards that may solve or provide a pathway to the current interoperability problems faced[5,6]. Figure 1 identifies the System of Interest for this report.

The literature review and approach of this report focuses on three areas; technology, standards / policies and public / political issues and perceptions[7]. First, the technologies being developed for military applications to solve their tactical interoperability needs offer promising applications for first responder use. This research found two viable technology candidates in the Joint Tactical Radio System (JTRS) program and the underlying Software Communications Architecture (SCA) that supports Software Defined Radios (SDR)[8]. JTRS is a military program to develop a standard set of radios for handheld, land mobile and aircraft applications. The goal of JTRS is to develop common radio hardware and software that allows each radio unit to function as a radio, computer and router on the battlefield. The SCA is a standard by which compliant common hardware can be loaded with software waveforms that provide functionality previously performed and constrained by the hardware. The second focus of literature review is standards and procedures. DHS provides funding, guidelines and standards to assist the first responder community in evaluating new technologies, creating operating procedures and conducting exercises to observe the effectiveness of those plans and procedures. A standard set of plans and procedures is perhaps the most important part of any solution as it allows the responder community to move towards a standard set of communications equipment operating within a predefined framework of policies and operating procedures. The final area of research focuses on the human and political issues of systems engineering of large scale technologies. This research includes radio spectrum usage issues with regards to available radio spectrum becoming available from the switch to digital television, jurisdictional issues between local and federal agencies and funding issues that face first responder agencies.

Executive Summary

Prompted by communications and interoperability problems during the September 11, 2001 attacks on the World Trade Center, the DHS initially set aside 968 million USD for the investigation, assessment and verification of public safety interoperability communications[16]. Many years have passed since these initiatives were started and results remain spotty with varying levels of success. Many jurisdictions still find themselves short of DHS expectations. Just as Global Positioning Systems (GPS) served as a disruptive technology within the positioning and navigation community expanding the technology into previously unintended markets, the JTRS effort can be leveraged to provide SDR and SCA technology solutions which will allow first responders to operate within a set of standards by having technology that allows their communications equipment to be compatible with any number of local, state or federal agencies. This technology combined with solid standards and training, will go far in moving towards real interoperability solutions.

Interoperability can be brought about through the use of SDR incorporating specific waveforms. A waveform is the entire set of radio and/or communications functions that occur from the user input to the radio frequency output and vice versa. One can think of a waveform as all the functionality between the antenna and the user, implemented with software. This technology would also pave the wave for future functionality such as emitter identification and self forming networks, removing the need for downloading pre defined work groups or command structures. Thus, a jurisdiction can create a set of response plans that define frequencies, command, control and assets given a particular incident that can be downloaded to each responder's communications gear.

Alternatives to this solution are to allow a portion of the 700MHz spectrum freed from the transition to digital television to be allocated as public safety spectrum. Expanded use of Fourth Generation (4G) and Voice over IP (VOIP) applications that are commonly used in commercial wireless applications can be supplemented to cover a transition period or provide solutions for rural responders.

Cost is a major consideration for local communities that provide funding for first responders. A typical decrease in technology costs over time combined with the research and development performed for military applications will drive costs downward. The DHS and federal government must insure steady, consistent funding while coordinating with jurisdictions to replace equipment as under normal lifecycle conditions. These are long term proposals and a reasonable plan in which non technical and current procedures are updated and employed while this technology is maturing. This would include radio swaps, shared command centers and well documented procedures and policies.
The technology proposed will also support future functionality of emitter identification, self forming networks and incident response plans tailored to location and incident type.

Background

The need for better interoperability during major incidents was first identified in the 1995 aftermath of the Oklahoma City bombing and further highlighted in the World Trade Center attack in New York and Hurricane Katrina responses in New Orleans. The technology issue is that local responders as well as federal agencies use disparate communications systems operating on different frequencies. This creates a need for the responders to work though a dispatcher or several layers of agency personnel to relay information and coordinate assets. This creates a command and control issue that is further hampered by a lack of standards and protocols across agencies.

The United States (US) military has created the JTRS program which uses SDR technology that allows SCA compliant radios to be loaded with waveforms allowing the user to communicate on different frequencies using a common hardware platform[9,10,11].

There are also sets of standards that the DHS and the Association of Public Safety Officials (APCO) have created that allow equipment manufacturers to develop radios that meet these standards. First responder equipment, training and evaluations are all measured against these standards. Discussed later in this report are standards such as P25 and SAFECOM that define interoperability plans, documentation for measuring progress and planning exercises. There are templates for the creation of Standard Operating Procedures (SOP) and State Communications Interoperability Plans (SCIP). These form the backbone upon which a technology solution can operate.

The public safety community has also been approaching the Federal Communications Commission (FCC) to allow the 700MHz portion of spectrum available to be used for common first responder channels. This would serve as an alternative solution. While the focus of this report is on communications, the supporting standards and human issues are discussed as well because these will serve to help or hinder any technology solution. In developing a sound solution, the systems engineering analysis involves the development of requirements, architecture and verification methods. Using this broad approach will allow responders to effectively work together and spend their time assessing and helping, not trying to find a way to speak with each other.

Table 1 – High Level System Requirements

High Level Requirement	Type	Verification Method
The first responder locality shall have standard operating procedure(s) (SOP) that are compatible with and cross referenced to the state's Statewide Communications Interoperability Plan (SCIP)	Operational	Plans review and approval
The SOP shall address each incident type and agency that the responder may need to operate with.	Operational	Plans review and approval
Training scenarios shall be performed bi-yearly and exercise certain incidents that verify the local and statewide SOP.	Operational	Documented after action reports including lessons learned.
Software Defined Radios (SDR) purchased shall be Software Common Architecture (SCA) compliant.	Hardware and Software	Vendor certification
Waveforms and software developed for the SDR's shall be P25 compliant.	Software	Vendor certification
The SDR shall have the capability to be reprogrammed at the shop level with future capability of being reprogrammed over the air.	Hardware and Software	Vendor certification
SDR shall meet existing Form, Fit and Function for handheld, land mobile and dispatcher use.	Hardware	Purchase specifications
The database shall be capable of storing waveforms.	Software	Acceptance testing
The SDR shall interface with existing dispatch systems	Hardware and Software	Acceptance testing
Radios shall operate at or greater than the current operational hours of the radios being replaced.	Reliability	Vendor certification
The SDR shall meet all applicable MIL-STD 810 environmental requirements	Reliability	Vendor certification
SDR shall have the capability of being repaired and maintained by existing shop personnel.	Maintainability	Vendor certification
Equipment purchases shall be given consideration to support GPS, video, networking, emitter ID, etc.	Future	Purchase specifications
The database shall store a list of emitter waveforms that the SDR can identify.	Future	Acceptance testing
The SDR shall have the capability to cross patch with the Public Switched Telephone Network (PSTN).	Future	Acceptance testing
The software developed for SDR shall have the capability to define and develop response plans to tailor waveforms.	Future	Acceptance testing
The SDR shall have the capability to identify other first responder emitters in the operations area and select the appropriate waveform to use in a given scenario.	Future	Aceptance testing

Requirements

Table 1 is a listing of high level system requirements for improved interoperability for first responders[11,12]. The table documents the requirement, type and method of verification. At this level, it includes technical and operational requirements as well as system requirements such as reliability, maintainability and standards. The operational requirements deal with the successful operation of the system. Hardware and software requirements deal with their respective specifications. Reliability requirements specify the probability of the system not failing during an operation. Maintainability requirements specify the capability of the system to be repaired and maintained by the personnel who operate the system. In the future requirements, the future expansion, and potential growth of the system is discussed. As is typical of large scale systems, these high level standards would serve as the foundation to develop more detailed software, hardware and standards specifications. In this system, verification methods would rely less on acceptance testing and more on vendor certification and planning approval. The first responder community procures equipment more often than not, based on vendor certification and documentation approval rather than acceptance testing that is prevalent in the defense industry. Giving structure and guidelines to these requirements are good quality standards.

Standards

Although requirements can be well defined, for first responder interoperability, the foundation upon which requirements are successful is the standards and policies that provide the underlying support. A *Frost and Sullivan*[17] report that DHS has defined six levels of interoperability.

Level 1	Radio swaps
Level 2	Talk around nets
Level 3	Mutual aid
Level 4	Gateways
Level 5	System specific roaming
Level 6	Standards based shared systems

These interoperability levels were created based upon a basic set of standards for each level of interoperability.

Work towards interoperability has tended to be disconnected, fragmented, and often conflicting. One of the first planning documents from DHS was the National Emergency Communications Plan (NECP). The NECP is an umbrella effort to promote the ability of first responder to communicate during major events with the end goal of creating nationwide interoperability. In order to coordinate various federal initiatives, the SAFECOM program was established. SAFECOM, a DHS program, provides research, development, testing and evaluation, guidance, tools, and templates on communications-related issues. Under SAFECOM, each state is required to create a Statewide Communications Interoperability Plan (SCIP). The SCIP provides states an approach to building and implementing a strategic interoperability plan. The National Institute of Standards (NIST) works with DHS to identify and develop standards for wireless data, networking and communications system applications and technologies. NIST also provides facilities and test beds for evaluating these solutions and standards.

Also applicable to first responder interoperability is the National Incident Management System (NIMS) that the Federal Emergency Management Agency (FEMA) has in place to create a national approach to incident management. The NIMS standards provides framework for communications, resource and command management, multiagency coordination and preparedness. NIMS is applicable to first responders with regards to natural disasters and working with hazardous materials

The first responder communications community has an organization dedicated to public safety telecommunications. The Association of Public Safety Communications Officials (APCO) provides advocacy and technical guidance to the first responder community. In the early 1970s APCO developed Project 16. Project 16 created standards for the technical details and capabilities of emergency responder communications systems. While Project 16 succeeded in creating a basic set of functionality, it highlighted problems of interagency collaboration because frequency standards were never adopted. Several manufacturers built Project 16 compliant radios but in order for agencies to communicate with each other their systems needed to be patched together. APCO Project 25 (P25) started in the late 1980s to address digital radio communications, including 800MHz trunked systems. P25 is actually a set of standards that improve interoperability by defining hardware, software and interfaces. DHS requires migration to P25 and federal agencies purchase P25 compliant radio equipment. State and local jurisdictions have been slow to migrate due to funding issues. SDR P25 waveforms have been developed and tested for first responder use.

The Software Communications Architecture (SCA) standard provides an open architecture for hardware and software on a SDR platform. SCA is the basis for the military JTRS[13]. Existing first responder training standards are to be integrated within any system solution. This allows the technical solution to meet the needs of a given incident based upon the training that the responders have been given. Conversely, the training received should include the use of SDR and associated technology so the capabilities are known and applied when needed.

Architecture

A well constructed system uses an architecture that takes the requirements and standards and can support them effectively. The physical architecture of a first responder system is shown in Figure 2. High level requirements have been discussed along with the applicable standards and procedures. Now the physical architecture can be defined. The physical architecture of this system is made up of three components, the database, hardware and software. A fourth component, future architecture is considered here as well.

In this architecture, the database is central in keeping all relevant information. The database is structured so that information can be queried and data constructed to support the first responder, the incident being managed and the appropriate SDR waveform. The database will keep and record a listing of all first responders and their assets such as equipment type and agency capabilities. Included will be the type of specialized training that agencies have provided to their responders such as diving, hazardous materials, specialized rescue or nuclear/biological. This type of information is useful in creating an appropriate command and control structure insuring that the correct assets are applied and managed during the response.

The hardware portion of this architecture provides a common platform for the appropriate waveforms and radio type. Typically, there are three classes of radio hardware, handheld, land mobile (vehicle, boat or aircraft) and a desktop that a dispatcher uses. Each has SCA compliant hardware capable of being programmed and controlled via the waveform. From the database, the waveform can be constructed based on radio type, intended use and incident type or responders from a different agency. There is also a hardware component that allows this system to be connected or patched into other communication systems like telephone or other legacy radio systems.

The software component of this system provides the waveform that performs the SDR functionality. There is also software that is used to program and monitor the performance of the radio and the Real Time Operating System (RTOS) on the radio processor board. Taking the correct data from the database and determining what radio and incident type is needed, the waveform can be generated and loaded. Another piece of software is the software for patching into legacy telephone systems.

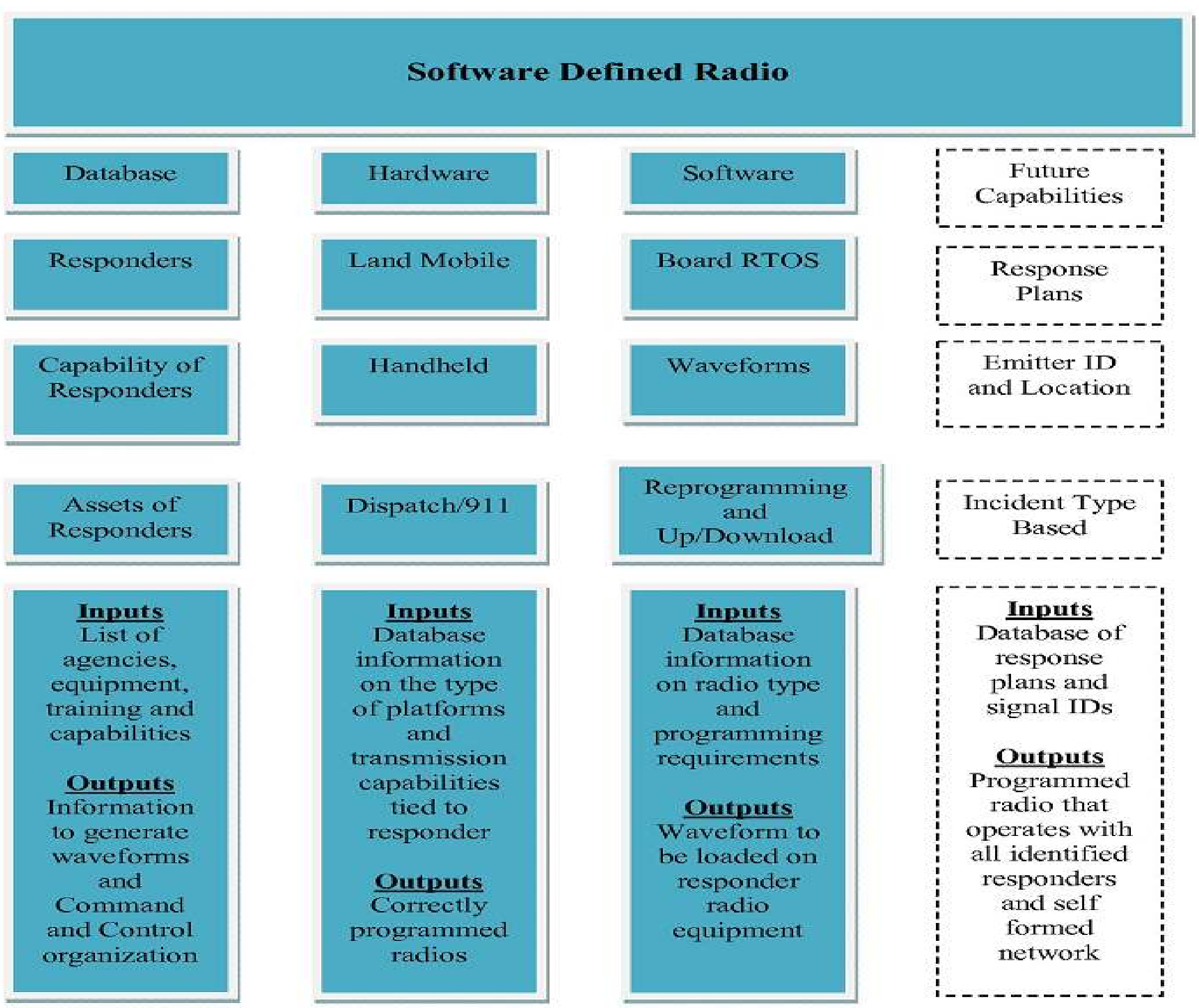

Figure 2 – Physical Architecture

Future architectural elements include the creation of response plans, emitter identification, incident type based waveforms and network configuration and integrated GPS. The automatic emitter identification would allow quicker and easier formation of networks and application of appropriate waveforms. The incorporation of GPS and asset tracking will also greatly enhance responses and safety by having the ability to track personnel and assets during an incident.

Systems Engineering

The *INCOSE* definition of Systems Engineering is "*An interdisciplinary approach and means to enable the realization of successful systems*[15]." Thus far the technical aspects of this system have been discussed. In this section some of the more holistic elements of this system are discussed, such as the political, human costing issues[18].

The DHS definition of interoperability is "*…the ability of emergency response agencies to talk to one another via radio communication systems, to exchange voice and/or data with one another on demand, in real time, when needed and when authorized*."[19] At first glance that statement may appear technical in nature but considering all the aspects of first responder interoperability, more than just technical issues must be explored. Like many large scale systems, to truly understand the problem being solved the solution must be considered a "system of systems" with each system, hardware, software and standards being a contained system themselves. Running through each of those systems are the human and political factors.

In this first responder system there are stakeholders who each have their own priorities, agenda and goals. For this system, the stakeholders and their interest in this system are;

- *US Federal Government* (Security, verifying safety and environmental standards.)
- *State Government* (Security, cost; regulation; public perception and adoption.)
- *Local Government* (Safety; cost; performance; availability; utility)
- *First Responder Community* (Cost; regulations; capacity, demand)
- *Public* (Cost; safety; capacity, demand, regulation)
- *Communications Industry* (Cost; safety; demand, regulation)

The political aspects to consider with this system are public safety, public perceptions, costs, and funding and spectrum availability. While DHS has taken the lead in working with state governments to increase operability funding of those programs is at the discretion of congress and always in danger of being decreased or cut entirely. And, federal funds always come with some level of control or direction that may be at odds with state responders. Along with funding are costs of this system. When technology such as SDR is used there are large development costs and long lead times before significant results can be realized. Finally, the federal government, through the Federal Communications Commission (FCC), controls radio spectrum. Spectrum is divided among users, private, commercial and public safety. While most of the spectrum that became available from the switch to digital television was auctioned at a considerable sum, a block was not because only one bidder emerged. The public safety community lobbies the FCC for the spectrum to be dedicated to public safety; the FCC still has not decided what to do with this portion of the spectrum[20].

Jurisdictional issues also play a part in this system. Not only are the technologies varied among agencies but the standards, training and legislation is varied as well. Each state has its own set of protocols and criteria for first responders. And even within each state there are townships and counties that have their own set of standards and requirements. In some states, fire and ambulance services are provided by volunteers while others have paid services. Through training and regular exercises, particularly tactical, pre-existing relationships can be created that aid future interoperability. And, along with jurisdictions come the natural tendency to guard one's turf in matters of responsibility, funding and recognition.

SDR is an emerging technology that promises to solve the technical issues of interoperability. However, with any new technology there are issues of maturity and cost. Emergence behaviors of its use and prevalence in the industry should be monitored closely as new and yet unknown uses of SDR may materialize that leap frog the existing SDR capability and drive costs down while increasing functionality.

Risks and challenges are an important consideration in any system engineering analysis. Here, the risks are the SDR technology maturing and the associated costs that may make SDR technology out of reach of many first responders. Good planning and risk mitigation will help agencies with long range goals and DHS compliance. The challenges will always remain the complexity of solving this problem. Not only is SDR a somewhat complex solution, complexity increases with an increasing number of agencies involved trying to work with each other. Testing and verification of these solutions in a real world training situation will help to measure success, gain valuable feedback and create a roadmap for interoperability solutions.

These issues, in concurrence with the SDR technology, standards and procedures should also be part of any systems engineering solution. Excluding them in any analysis would be shortsighted as without these considerations, even the most technically superior solution will fail.

Case Studies and Use Cases

The use case and after action reporting that best illustrates the problems in interoperability and the conclusion of this paper is the October 2002 District of Columbia area sniper case. Over the course of three weeks there were 15 shooting incidents. At its peak, there were 27 separate law enforcement agencies involved in the investigation. As stated previously, complexity increases with the number of entities involved. This complexity required multiple solutions.

The solutions employed were the use of a cross patch between a legacy Ultra High Frequency (UHF) system and a state 800MHz system, three audio cross connect racks, use of a legacy UHF mutual aid system, radio swaps and the use of commercial wireless services. All of these solutions combined to further interoperability and improve tactical communications among the agency.

Some time after the case, DHS under SAFECOM standards interviewed all participants, including technicians and compiled operational and technical lessons learned[14]. Operationally it was determined that preexisting relationships provided a good foundation for solutions. This point was reemphasized in the interview performed[1]. Plain language rather than codes were required for all communications, voiding confusion, communications technical mangers needed to be in the daily briefing and debriefings providing an opportunity for quicker solutions or training of new personnel, prior communications planning enhanced operation but lastly it was stated time and again, that lack[3] of interoperability hindered the investigation overall.

Technically it was determined that the large geographic area and number of agencies required multiple solutions. It was found that interoperability between federal and state agencies were hindered because federal agencies use encrypted communications. Equipment training was critical to personnel who were given radios in a swap or were operating new equipment for the first time. Finally, the use of commercial wireless phones and push to talk equipment was valuable in relieving pressure on the radio communications by using the commercial equipment for administrative interoperability.

In the February 2009 report *National Summary of Statewide Communications Interoperability Plans*, DHS evaluated all 50 states with regards to the completion and effectiveness of their SCIP. It was found that most states had completed their SCIP but many were behind in performing regular exercises to verify those plans, did not plan for use of plain language communications in their plans and rarely updated those plans to reflect training, equipment or structural changes. As stated previously, these exercises are invaluable in establishing pre existing relationships. The fact that DHS has made available standards and templates has allowed the states to make progress in documenting their operating procedures but many states are still behind in verifying and refining those plans.

Alternatives

Given that SDR is new technology with limited experience outside of military use, a good systems engineering analysis would include research into alternative solutions. In the first responder community several alternatives are in fact being developed or under consideration.

DHS has a multi-band radio program in place with several units built and under evaluation in several pilot programs. The intention of this multi-band radio is to construct a radio that is capable of operating in five frequency bands that are common to first responders. There is also an option for four additional bands that would be capable of operating in federal bands such as Department of defense (DOD), Federal Emergency Management Agency (FEMA) and National Guard frequencies. This is a good step towards greater flexibility however this solution is still not flexible enough to address each given scenario on a larger scale. The capability to communicate with other federal agencies is still not present.

The use of common spectrum with the 700MHz band appears to be the most viable option. With the switch to digital broadcast television, several blocks in this spectrum were auctioned by the FCC. The last block only attracted one bidder so the FCC is delaying another auction. The public safety community has petitioned the FCC to allow this block to be used exclusively for the first responder community. This would be an opportunity for federal, state and local agencies to properly share and plan operations on a frequency that they can share and operate common equipment.

The next alternative is the use of commercial wireless applications. Push to talk and voice over IP in combination with third and fourth generation networks would allow for not only communications but the exchange of data and video. Many incidents have shown that the use of commercial wireless has greatly helped and supplemented communications. For instance, the second World Trade Center attack destroyed not only police and fire communications but command and control centers as well. Commercial wireless was used to fill in coverage gaps during initial operations. The reliance on commercial applications solely, is a risk that needs to be considered. There is also the expense of monthly access rates and bandwidth limitations.

The last viable alternative is the expanded use of 800MHz digital trunked systems. While many smaller or rural agencies use Very High Frequency (VHF) systems, larger agencies have switched to 800MHz systems to correct coverage and capacity problems. This system allows interoperability with neighboring jurisdictions or the programming of access channels with compatible equipment. This helps in localized incident responses but still does not help with larger incidents when federal agencies may be involved. As discussed previously, the solution lies in a combination of alternative technologies and standards and choosing those that allow for future expanded functionality.

Engineering Education

This study is an example application of the systems engineering methodologies that can be applied to address a number of real life problems. The tools are taught as part of the systems engineering graduate level curriculum. The broad areas where systems tools are taught include system analysis and design, operations optimization, applied economic analysis, systems architecture, and simulation and modeling. This helps students understand and embed the efficient processes and procedures into front line operations. Students are tasked to pick a few tools and methodologies and use these tools to apply them to address a real life problem. The tools / methodologies used in this study include requirements analysis, conformance, architecture development, and standards identification, use case analysis, analysis of alternatives and others. This encourages learning of the implementation of systems engineering in an educational environment. This technique of educating students not only helps them learn and retain the material, but it also helps address important issues. It provides a broad systems perspective to domain specific problems.

Future Work

With the many alternatives available to supplement the use of SDR, actually implementing an SDR solution allows for several future functionality enhancements. Work is being done using SDR to automatically identify transmitting radios in the area. By installing a database to compare waveforms to, each transmission can then be matched to known agencies allowing the smart radio to know what frequencies to operate within and how the command and control structure and network will operate.

Using software in the SDR technology will allow an agency to predefine what type of response is needed based on location and incident type. By having all known agencies, their assets and abilities documented and defined, would allow for customized response plans. This may save time by not having to determine required assets and manpower needs.

On the communications side work is being done to allow the SDR to roam, much like mobile phones do now, transparent to the user. The system, called Flexnet, allows a radio to select frequencies based on the surrounding infrastructure that it detects. Vendors are also working on incorporating a locating component into the radio allowing not only the sharing of data and video but also the location of the unit itself. There are existing standards, POSCOMM, that define this functionality. This would be a good utility as first responders have a hard time not only communicating within structures but being able to track others inside structures. So, while SDR is an emerging technology, it offers some future additional benefits for interoperability.

Conclusions

Progress in first responder interoperability is still slow and fractured. Although DHS has put in place standards and templates, there is still much work to be done in both technologies and planning. More so than the technology, money is a driver in all first responder solutions. DHS needs to avoid the typical federal government action of enforcing standards and technology on local and state agency that don't have the funds to support them. Like many large system solutions, technology alone is not the answer. There is not a one size fits all solution for a given incident. First responders need to ensure that there are good standard operating procedures and training in place that can be supplemented by the technology. The technology, SDR offers many future capabilities when cost and maturity levels come within reach of state and local agencies. In the interim shorter term solutions need to be furthered such as using common spectrum or expanding 800MHz use. Standards for encryption need to be further developed as well. Federal agencies require encryption technology as part of the acquisition process. States and localities need to be incorporating this into the planning process as well.

Standards and operating procedures will provide a firm foundation upon which the selected technology can operate efficiently.

Recommendations

Based upon the research and systems engineering analysis, this report recommends that while SDR technology is an end goal of interoperability that technology needs to be slowly phased in while other areas are solidified. SDR research should be pursued at the state level and pushed down as needed and funding is available. Establishing good working relationships with other agencies will go a long way to creating effective plans and procedures for incident response. Establishing these relationships must be done through consistent training and exercises to test planning and procedures and update them as required. Regional databases need to be created and maintained that can be rolled up at the state level in the SCIP. The SCIP should accommodate multiple solutions as the case study pointed out. As risk mitigation, other alternatives such as shared spectrum and multi-band radios need to be further developed and tested.

Only when the firm foundation of standards, planning and training are put in place, can a technology like SDR be successful.

This case study is an excellent example of using to systems engineering tools and methodologies learned in a graduate systems level program. Similar techniques can be used to solve other real world problems.

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