# i-Axis Best Practices Guide to Indoor Mapping,Tracking, & Navigation

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NAPSG Foundation

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PSCR

LBS
PSCR LOCATION-BASED SERVICES

## Foreword

Technology can be an equalizer, crossing geographic, social, and economic barriers to allow greater freedom and innovation. Although the general population has embraced many advancements with open arms in all facets of daily life, the public safety community, although full of active drivers of technology use and innovation, as a whole often lags in adopting these technologies.

Convenience and a higher level of risk acceptance allow the public to take a chance on emerging technologies. At the same time, monetary incentives and market share drive vendors to design applications and technologies to reach the widest possible market. These two factors tend to distance public safety professionals from emerging equipment and applications that can improve response times, provide situational awareness, and increase positive outcomes for the public.

The success of augmented and virtual reality platforms, secure video sharing and messaging applications, and Internet of Things (IoT) devices should pave the way for universal adoption in the public safety community. Unfortunately, since lives are at stake, these disciplines cannot be beta testers, victims of an unsecure or untested application that could lead to a data breach, or use a faulty product.

The need to identify emerging technologies and bridge the gap between operational personnel and developers will expedite this adoption process. Current advancements, such as utilizing GIS for indoor preplans, have started to replace traditional paper maps and building blueprints. Future advancements such as hyper reality helmets, biometric and inertial devices, and IoT data integration will truly usher in an age of unparalleled situational awareness.

We should not wait for a paradigm shift to put these tools into the hands of public safety professionals. Why the urgency? Just one example, certain line-of-duty deaths shows a gap in spatial awareness that have been overcome already in other industries.

Imagine a typical day of a "connected" home and person. Your alarm goes off and prompts the lights in the house to increase brightness slowly. Your coffee machine starts when you roll out of bed, and your thermostat automatically increases the temperature in the house. When you leave for the day, your smart locks and garage door opener identify that you have left the house and automatically lock up. During the workday, you receive notifications that your package was delivered from your security camera, and that your smart irrigation system will skip watering the next day because of forecasted rain. This type of device adoption and integration is becoming more common in the general public.

Public safety should have the same realistic expectations of devices and technologies all the way from pre-planning and mitigation, to a call for service, demobilizing, and conducting after-action reviews. Whether it is accessing building floorplans and hazardous material locations, locating casualties in a multi-story building, or providing directions to an injured responder, mapping, tracking, and navigation best practices can be implemented today, and folded into policies and procedures for years to come.

We hope this guide provides a snapshot of current best practices and allows responders, academia, researchers, and manufacturers to work together to accelerate the adoption of these technologies. Instead of being impressed with how far we have come, be inspired to innovate for the future.

NAPSG Foundation Team
LBS Working Group

## Introduction

Mapping, tracking, and navigating indoors is one of the greatest challenges facing first responder safety today. The built environment is growing both in volume and complexity – increasing the potential frequency of public safety response to 911 calls made within structures where locating victims poses unique challenges. Today more than ever, first responders need solutions to provide better situational awareness indoors, equipping them with necessary capabilities to operate effectively while maximizing responder and citizen safety.

Two problems arise while trying to address this challenge. First, responders are not rapidly adopting and using the existing location-based services (LBS) solutions and capabilities available today. Second, research and development teams do not have actionable input from first responders to develop the practical solutions of tomorrow.

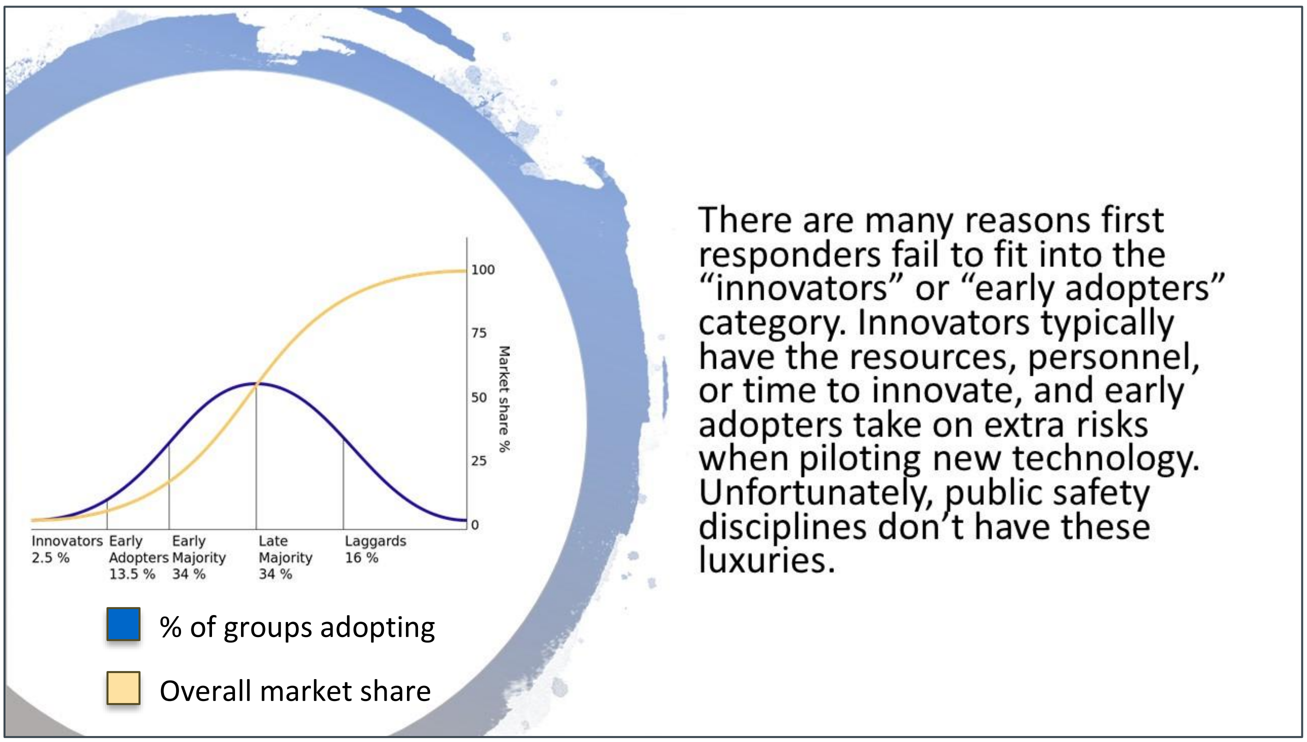



*Figure 1 Diffusion of Innovation*

To address both problems, we must help first responders take advantage of LBS technology by facilitating integration into their policies, standard operating procedures, training, and daily use. Secondly, we need to define the most critical technology gaps identified by the public safety community as a basis for prioritizing research & development (R&D) investments.

## 1.1 Purpose

The National Institute of Standards and Technology (NIST) Public Safety Communications Research Division (PSCR) considers the information axis, or i-Axis, to be the abundance of data generated from the internet of things (IoT) devices and other data sources that may be consumed for public safety use.

This i-Axis Best Practices Guide to Indoor Mapping, Tracking, and Navigation (hereinafter referred to as the Best Practices Guide) seeks to accelerate the adoption of LBS by providing first responders with a resource to start or improve their current programs.

To develop this Best Practices Guide and target “early adopters,” a survey to identify LBS Innovators was launched. These “early adopters” are the individuals working within agencies who encourage innovation but are looking for tangible examples before making definitive choices. Early adopters tend to be more discreet than innovators in adoption choices, but also are highly influential to promulgating use among other agencies once a solution is proven.

With over 100 responses, the trends and gap areas were identified, ultimately informing the sections within this Best Practices Guide. This outreach also served as a kickoff to forming the LBS First Responders Working Group, a group of experts made up of representatives from law enforcement, fire, emergency medical services, emergency management, the private sector, and the military.

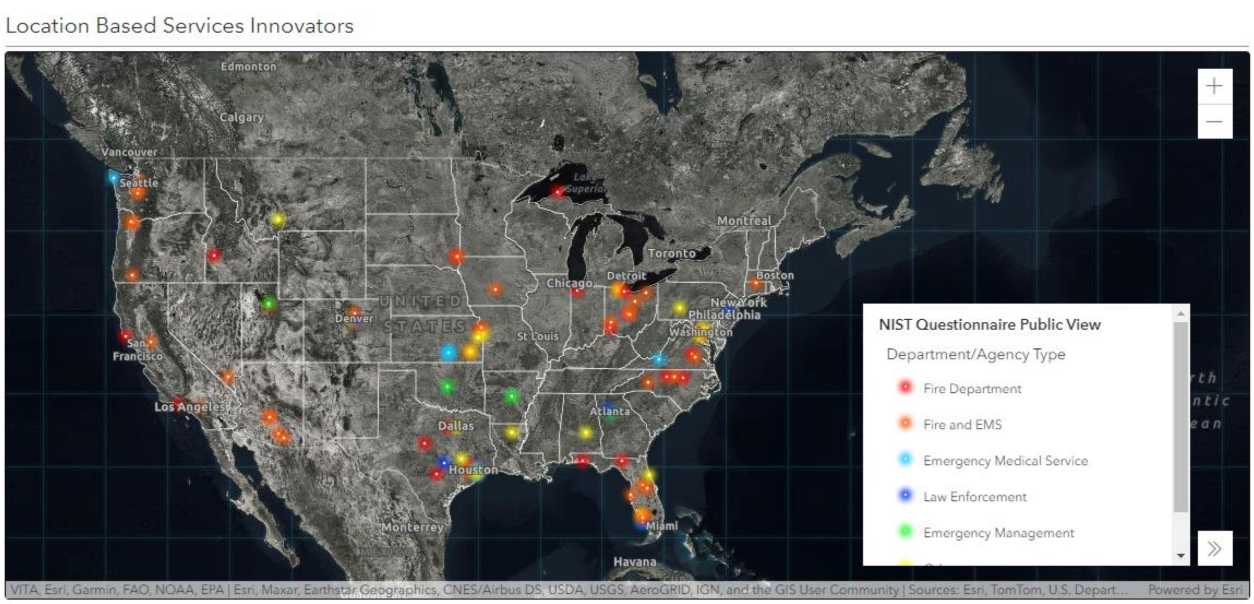



*Figure 2 Map of LBS Innovators*

Early adopters will often use the early work of innovators to develop best practices and then provide detailed requirements to solution providers prior to making investment and procurement decisions (Rogers, 1976). In the process of developing the LBS early adopter community, it is important to provide the research and development (R&D) community with clearly defined requirements to facilitate consistency and ensure interoperability among solutions.

## 1.2 Process for New Best Practices

The first iteration of the Best Practices Guide was developed by the LBS First Responders Working Group, subject matter experts in the field of indoor mapping, tracking, and navigation, and through a public comment period facilitated by NAPSG. The Best Practices Guide will be revised yearly to include any revisions, new best practices, or removals of best practices that no longer are accepted in the industry.

Unlike traditional best practice guides which seek to consolidate the abundance of standards available, indoor mapping, tracking, and navigation is very much a new endeavor. The process of arriving at a best practices guide to inform first responders, technologists, and decision makers looking to innovate is critical to ensuring that the guide continues to provide value and reflects changes in the operational environment.

The submittal process outlined below is designed to be flexible and collaborative. The process allows submissions for both new best practices and recommended changes to already approved best practices.

**Best practice submitted by public or staff**

Best practice submissions enter the process by filling out the Best Practices Guide Form. Anyone can submit a best practice, including staff, working group members, or the public.

**Staff reviews document (admin review)**

Staff will conduct an administrative review on all submitted best practices. The administrative review will look at form completeness, ensure that all supporting documents are attached, and validate that the best practice submitted is part of the guide. If the administrative review is successful, the best practice moves on to the stakeholder body for technical review.

**Stakeholder body aproves the best practice? (technical review)**

The stakeholder body will meet quarterly (virtual) to conduct a technical review on all best practices that have made it through administrative review. The technical review is an opportunity for experts in the field of the submitted best practice to evaluate the merits of the submission and decide whether it is a currently accepted practice. The stakeholder body may accept the best practice, reject the best practice, or return the best practice for additional information and resubmittal.

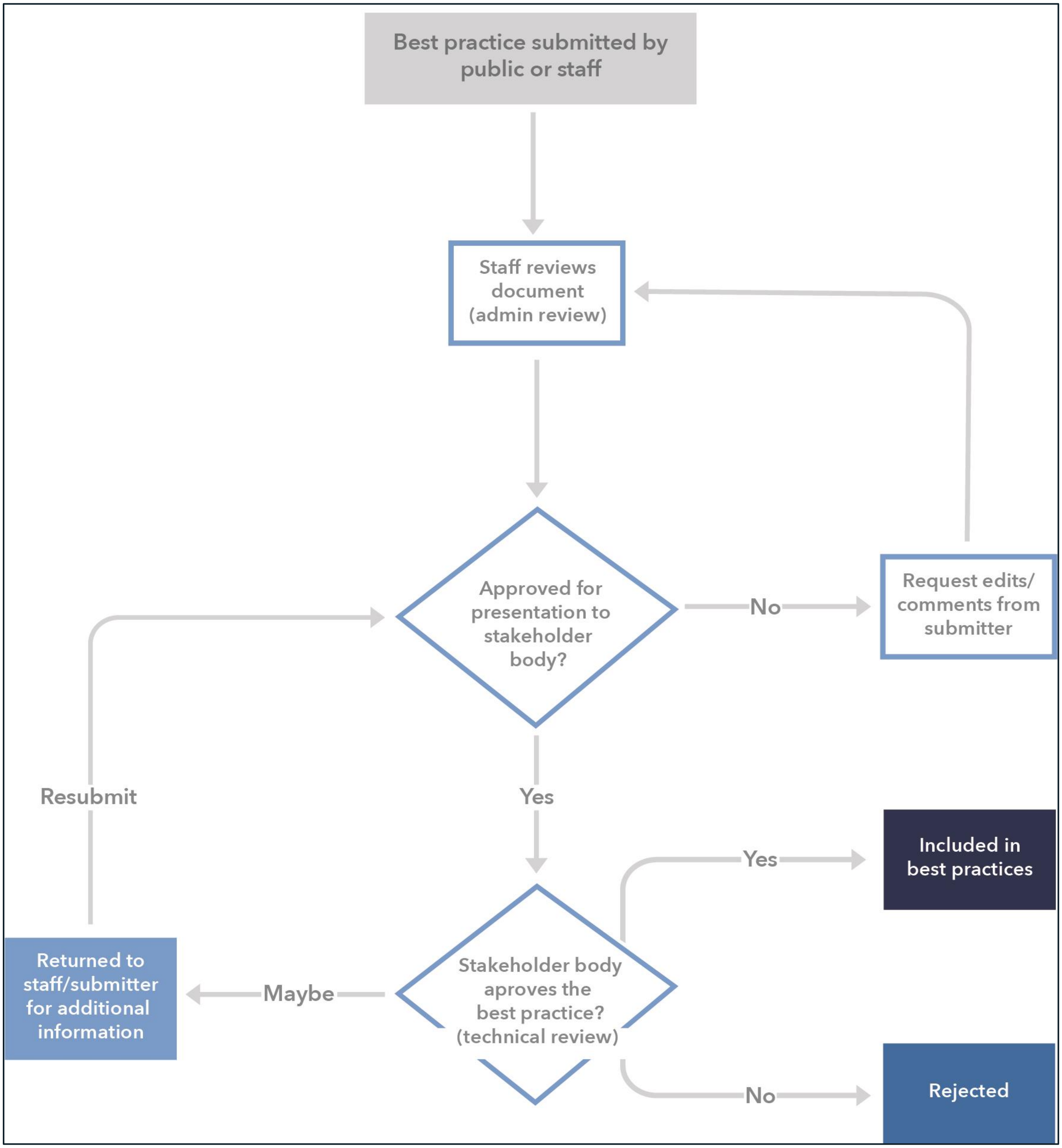



*Figure 3 Best Practices Guide Submission Workflow*

## 1.3 How to Use the Guide

This guide is meant to provide a roadmap to agencies looking to implement or improve their indoor mapping, tracking, and navigation programs. The purpose is not for users to progress through the guide linearly; instead, this guide seeks to capture best practices as they are today and direct users to reference material. Each section provides a best practice statement, description, and further reading section:

**Statement:** What the best practice is addressing.

**Description:** A more detailed look at the best practice, including the recommended components to include policy, governance, technology, and other domains.

**Further Reading:** Documentation used to inform the best practice, including technical reports and other guides.

A second way to utilize the guide is by position or role. The recommend audience for each section is:

**Statement:** Decision makers, executives, policy groups, supervisors

**Description:** Power users, subject matter experts, functional roles (e.g., pre-plan manager, Special Operations Commander)

**Further Reading:** Technologists and those responsible for implementation

This guide strives to be discipline and platform agnostic, but at times best practices are only available for a specific discipline. Readers are encouraged to do further reading on areas of interest and work with their peers to implement tactical and technological processes. Regardless, even discipline-specific best practices offer value and insights for those outside of that discipline.

The layout of the guide is also important. Overarching themes such as audience and governance impact all three sections. Within each section, the individual best practices are also layered. For example, you must start with a symbol (Section 2.1) before you give it attributes (Section 2.2).

Finally, this guide is not meant to be a technical implementation document. Reference material found after each section expands on the material and links to technical documents.

# Common Themes

## 1.4 Audience

**Statement:**

All aspects of mapping, tracking, and navigation should be developed with a multidisciplinary and whole community approach.

**Description:**

*Mapping*

When considering indoor mapping products, it is important to understand the various use cases, including special event planning, critical incident or mass casualty incidents, typical response operations, and training opportunities. Various viewpoints should be taken into consideration from the team responsible for creating and consuming these products, including:


*Figure 4 Whole Community NIMS*

- Law enforcement
- Fire
- EMS
- Dispatch
- Hospitals
- Private sector (private security)
- Special teams (SWAT, hazmat, structural collapse, etc.)
- Emergency Management

Within each stakeholder group, it is important to remember the various audience levels, including line-level, supervisory, command and control, and policy level/executive. Additionally, the uniqueness of public safety organizations should be taken into consideration, such as:

- Police Department vs. Sheriff's Department
- Urban vs. rural jurisdictions
- Career vs. volunteer organizations

Although indoor mapping products are typically consumed by first responders, the whole community may utilize pieces of information for a variety of uses. When possible, plain language should be used, and acronyms should be avoided.

*Tracking*

Tracking personnel and equipment is still an emerging field. Although equipment tracking, namely vehicles, has been around for years, it was typically done via dispatch centers and rarely displayed geospatially. Automated Vehicle Location (AVL) technology best practices can be found as a result of extensive testing by departments of transportation and provide a potential roadmap for indoor tracking (AECOM, 2018).

Tracking personnel should be used in conjunction with indoor maps. The usefulness of tracking personnel by audience may include:

- Dispatch: Provides better situational awareness, resources on scene or available, and personnel accountability.
- Responders: Provides better responder safety by locating mayday or officer down calls.
- Special teams: Provides situational awareness for areas that have been cleared. For example, SWAT teams typically conduct very methodical searches during active threat scenarios, and structural collapse teams utilize similar techniques.
- Emergency Management: Provides situational awareness regarding resources and the possible need for contingency plans.

*Navigation*

Navigation technologies are common throughout public safety, but the ability to navigate within a building is not as mature as navigating in the outdoor environment. Specific audience questions may include:

- Discipline differences: Fire personnel typically arrive on scene as an engine company with multiple people, whereas law enforcement vehicles typically have a single officer. The ability to have dedicated personnel to read a map and route resources for each discipline, especially en route, is different.
- Incident differences: Routing indoors to a non-life-threatening call for service is different than an active threat call for service. One call may require the responder to navigate themselves, and the other call may require a dispatcher or incident commander to provide directions.
- Routing the public: Providing routing instructions to the public in the event of an evacuation order, identifying possible safe rooms, and even allowing the public to better navigate themselves during special events should be a capability in a navigation program.

**Further Reading:**

Law Enforcement Best Practices: Lessons Learned from the Field

Building a multidisciplinary team: AWR-213 Critical Infrastructure Security and Resilience Awareness

Plain Language Frequently Asked Questions (FAQs)

Utilization of AVL/GPS Technology: Case Studies

## 1.5 Governance

**Statement:**

Mapping, tracking, and navigation programs should be built on governance consistent with agency policies and procedures.

**Description:**

The Best Practices Guide is not intended to be used as governance. However, it is important to recognize the role that governance plays in indoor mapping, tracking, and navigation and the challenges users may face.

Additionally, disparate systems require a governance and technological approach to address interoperability issues. The need to perform some sort of data transformation may be required for mapping, tracking, and navigation systems.

*Mapping*

Some topics to consider when implementing a mapping program include:

- Indoor mapping assessments
  - Types (Crime Prevention Through Environmental Design, Fire Inspection, Regulatory, Infrastructure Survey Tool/IP-Gateway, etc.)
  - Frequency
- Product access and information sharing
- Data security

*Tracking*

Tracking vehicles may already be present in organizations and have associated governance. Public Works and Road & Bridge typically have fleet management systems to track vehicle location, speed, mileage, and other metrics. Many fire departments and law enforcement agencies also use automatic vehicle location (AVL) to track equipment and dispatch based on closest unit. However, equipment tracking does not easily transfer over to personnel tracking.

Some topics to consider when implementing a tracking program include:

- Type of tracking devices (expanded in the equipment section)
- Data security
- Union rules

- Freedom of Information Act (FOIA) or equivalent state open records requests
- Responder safety

*Navigation*

Governance associated with navigation depends on the type of navigation technologies, who is providing directions, outdoor to indoor transitions, and operational environments. Navigation technologies already assist in closest unit dispatching, rerouting resources, and providing estimated times of arrival.

Some topics to consider when implementing a navigation program include:

- Current technologies: Does the current CAD vendor provide outdoor or indoor routing systems?
- License costs: Will the agency use a proprietary navigation system or an open-source system?
- Navigation directions: Is the responder navigating themselves using wearable devices, mobile devices, or heads-up displays? If not, is dispatch providing turn-by-turn directions?

**Further Reading:**

What is Data Transformation?

# Mapping

## 2.1 Symbology

**Statement:**

The symbology used for indoor mapping is consistent with outdoor mapping symbology. If no mapping symbology is present, an industry standard is utilized.

**Description:**

There are several categories that can be used to organize information related to a building. Most building diagrams use vector-based graphics to render symbols and design related to a building. These are done with either a computer-aided design (CAD) based file, or a geographic information system (GIS) based set of layers.

The 3 main types of geometry in both CAD-based files and GIS-based layers are:

- Points: A location that is represented by an x and y coordinate in a Cartesian coordinate space.
- Polyline: A vector feature that has an x and y starting point and then connects to a different x/y location. In the 3D environment, a z point will also be present.
- Polygon: A vector feature that has an x and y starting point, connects to multiple different x/y locations, and then connects to the original starting point.

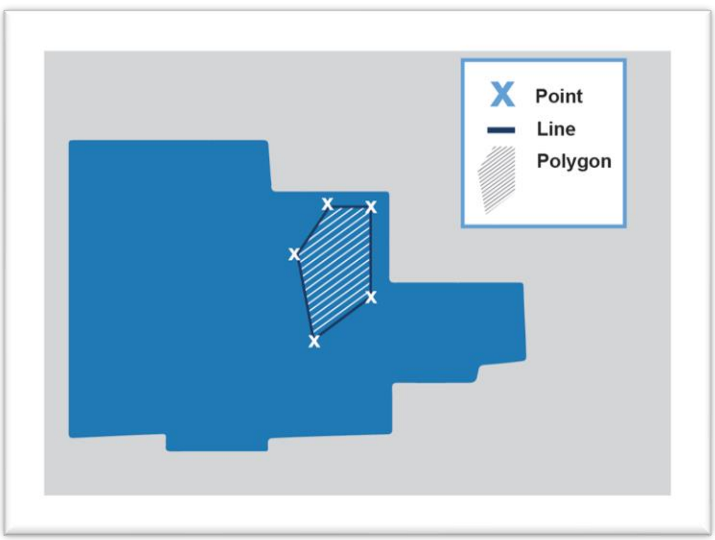



*Figure 5 Point/Polyline/Polygon Representation*

In a building, features can be represented by multiple vector types. For example, a piece of furniture can be represented by a point for location, or a polygon indicating the area of a feature.

*CAD-Based Files*

CAD based files are the dominant graphic files used to create building diagrams (CNC Cookbook, 2019). CAD files are single files that include some kind of "layer" attribute that allows for categorizing common features. This has been the preferred choice for file formats for architecture and engineering professionals for quite some time. In CAD files, features are represented with lines; this is because features are "drawn" into the diagram. For example, a wall would be drawn as a line but may be a double line to indicate wall thickness.

*GIS-Based Layers*

Using GIS to represent building information is a relatively new trend. Due to the improvement in computing processes and data availability, GIS has become more common over time. While GIS can be like CAD in that they both can represent vector graphics, GIS combines "layers" from multiple data sources and renders it in one common map frame. The benefit of using GIS for building mapping includes:

- The ability to change symbols as needed since all common features are represented.
- The ability to use data from other sources such as a hydrant layer from a water utility.
- The ability to use sensor data that is geographically enabled.

*Symbol Categories*

Regardless of how a feature is represented (point, line, polygon) they should be categorized. The reason you need to categorize features includes:

- Selecting which features are visible to a specific user or need.
- Organizing features to be represented by a common symbol or design.

Public Safety relevant features and building features can be grouped into categories. These categories can include:

- Access: doors, stairs, elevators, escalators, etc.
- Fire Suppression Features: fire department connection, standpipe connection, sprinkler riser, fire pump, etc.
- Secured Access Features: key box (Knox, Supra, etc.), key vault
- Utility Shutoff: electric, gas, water, etc.

- Hazardous Materials:  features represented by NFPA 704, possible DOT placarding, or container
- Hazards:  Subject features that may cause harm to a responder
- Building Systems:  Ventilation systems, alarms, detectors, special fire suppression systems
- Room Type:  Assembly, circulation such as hallway and entrance, mechanical, vertical spaces
- Wall Type: Masonry, drywall, conduit
- Location Type:  These are named locations within a building.  Examples include retail spaces, offices, manufacturing, bathroom, etc.
- Passageway type:  Hall, entry, etc.

*Symbol Shapes*

As stated above, a feature can be represented by more than one type of shape. Below are some examples of features based on either a point, line, or polygon.

Symbols associated with points:

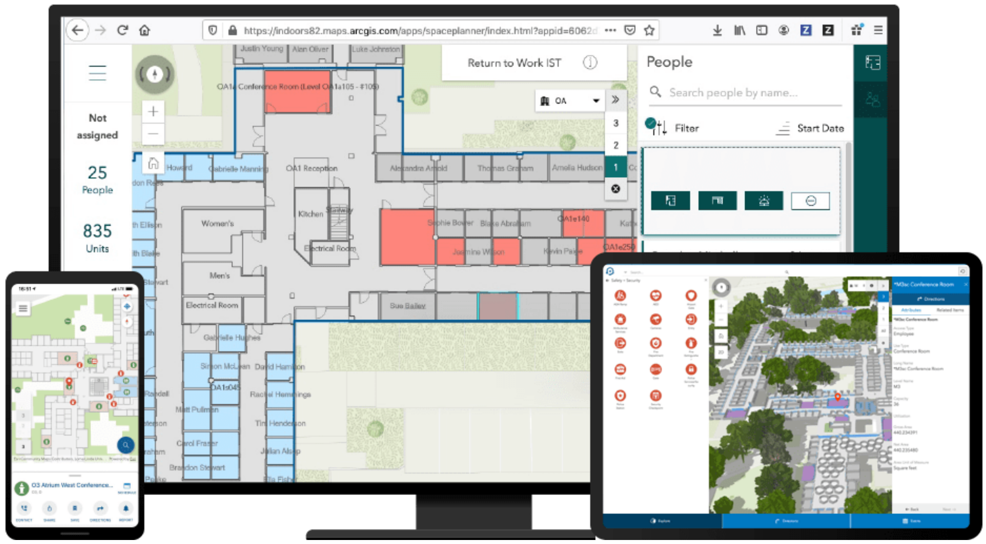
- Alarm panels
- Key Box
- Entry Point
- Elevator
- Electrical Shutoff

Polylines:

- Fences
- Walls
- Fire Walls
- Internal paths like hallways

Polygons:

- Pavement footprint
- Rooms
- Water
- Pathways
- Building footprint



*Symbology for mapping indoors:*

When mapping indoors, and as technology evolves, new symbols and graphical representations will be required. IoT devices such as occupancy sensors, smart thermostats, or connected smoke/carbon monoxide devices will need to be mapped.

**Further Reading:**

[National Fire Protection Association 1620]

[NAPSG Symbol Library]

## 2.2 Attributes

**Statement:**

Location (x, y, and z) and description attributes should be collected for all points, lines, and polygons.

**Description:**

A symbol is a graphic representation of a geographic feature. Attributes are the data behind the symbol that allows for more information to be delivered to the user.

Symbol


Attributes:

- AED Manufacturer
- Last inspection date
- Location (coordinates, office #, etc.)
- Equipment included (pads, razor)
- Contact information for responsible party

Attributes are spatial and nonspatial information about a geographic feature and are usually stored in a table. Before collecting information, it is important to brainstorm and develop a game plan and data model of what information is to be collected for each feature and how it will be used. Data models typically organize elements of data and standardize how they relate to one another. Determine if the data already exists, or if new data needs to be created. Public Safety agencies create a lot of data, but other agencies (e.g., special districts, NGOs, utility providers) could have data that can be useful in the day-to-day operation of your agency. If the data exists, determine if the attributes meet your needs. Engage with the owner of the data to see if attributes could be added or updated.

If data needs to be created, start with an established data model, and select or add to the preexisting model. A good place to start is ESRI's Local Government Model, or look at ESRI's Public Safety Community to see what is possible. It is important to revisit the data model and make sure the attributes that are being collected are providing the information needed.

**Further Reading:**

ESRI GIS Dictionary

ESRI Local Government Information Model

ESRI Public Safety Community Overview

## 2.3 Coordinates, Accuracy, Precision

**Statement:**

Both two-dimensional (x,y) and three-dimensional (x,y,z) coordinates should be collected for indoor locations and be as accurate as possible.

**Description:**

Coordinates are the measured location of a feature. Two-dimensional (2D) features are represented by an x and y coordinate. Three-dimensional (3D) features are represented by an x, y, and z coordinate.

*2D Coordinates:*

The Federal Communications Commission (FCC) has issued multiple reports and orders around x, y, and z-axis accuracy. For 2D coordinates, the FCC proposed that by 2020, 80% of calls will meet the 50-meter accuracy threshold. (FCC 15-9A1)

50-meters may satisfy outdoor mapping requirements but is inadequate for indoor mapping. When possible, x and y-axis coordinates for indoor mapping points, lines, and polygons should strive to be as accurate as possible (sub-meter accuracy), utilizing as-built drawings, building blueprints, GPS locations, latitude/longitude, or other technology to capture locations.

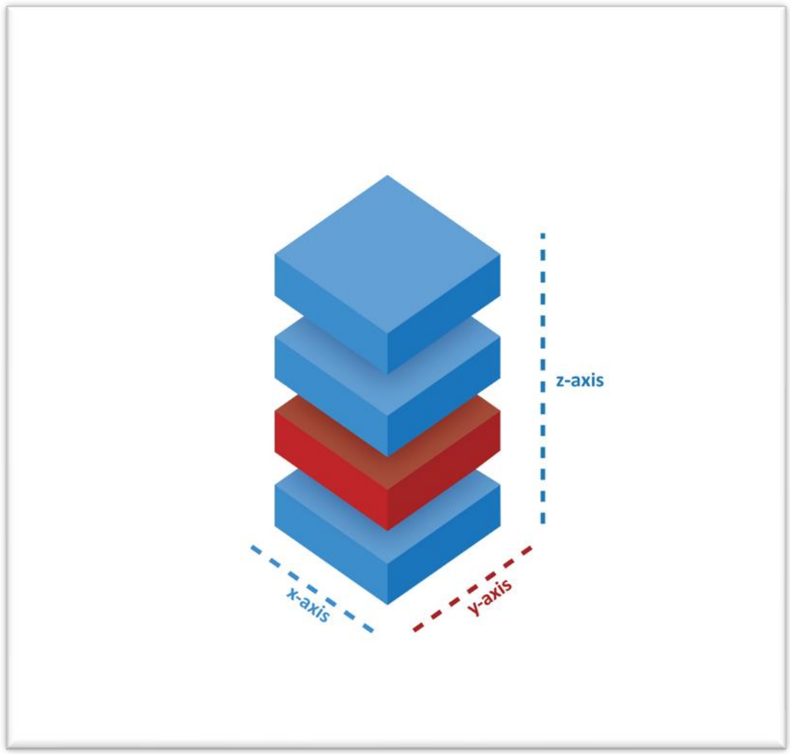



*Figure 6 z-axis representation*

*3D Coordinates:*

When collecting z-coordinates, a benchmark by the FCC for Wireless E911 Location Accuracy Requirements sets a 3-meter threshold. (FCC 19-124A1) A 3-meter threshold provides a consumer of a z-coordinate with a reasonable approximation of floor location.

When deciding how to capture and convey z-coordinates, it is important to pick a common method. The FCC has sought comment on the best method to convey z-axis information, including:

- Above Ground Level (AGL) vs. Height Above Mean Sea Level (MSL)/Height Above Average Terrain (HAAT).
- Height Above Ellipsoid (HAE): Heights reported from GPS are typically heights above ellipsoids and do not easily translate to orthometric heights.

In general, MSL works for outdoor environments, whereas AGL may be the preferred method for structures and interior spaces.

For example, a firefighter may respond to a home fire that is 50 meters above sea level (MSL), but only 1 meter above ground level (AGL), which would translate into the first floor. Understanding the floor where the incident is occurring greatly impacts equipment usage (ladder vs ladder truck) or the need for specialized equipment by law enforcement (bomb robots, entry locations).

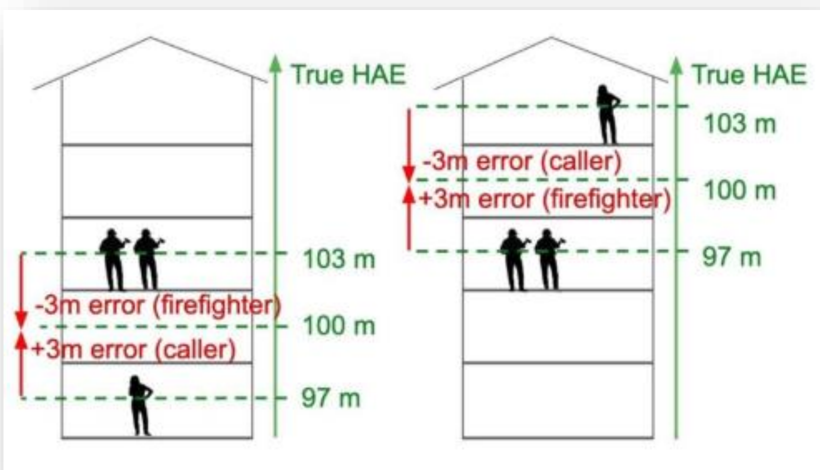



*Figure 7 Height Above Ellipsoid Representation*

*Importance*

Both CAD-based diagrams and GIS-based layers use coordinates to manage feature locations. The main difference between them are:

- CAD files generally do not use geographic coordinates in their files. CAD files can have real world coordinates attached as an addendum.

- GIS layers are based on a geographic coordinate. Geographic coordinates allow for the ability to use other related layers, place diagrams in context with their surroundings, and provide the "location standard" for other devices that use LBS.

Finally, when capturing 3D coordinates, a method to display distinct floors is required. Some applications allow floor-to-floor transitions by using floor selector tools. Floors can also be organized as distinct files.

**Further Reading:**

Fourth Report and Order and Fourth Further Notice of Proposed Rulemaking, Wireless E911 Location Accuracy Requirements

Fifth Report and Order and Fifth Further Notice of Proposed Rulemaking, Wireless E911 Location Accuracy Requirements

Sixth Report and Order and Order on Reconsideration, Wireless E911 Location Accuracy Requirements

Indoor Location Accuracy Timeline and Live Call Data Reporting Template

## 2.4 Outdoor to Indoor Transition

**Statement:**

Indoor maps should have a seamless outdoor to indoor transition. A first responder should be able to consume outdoor and indoor maps in the same application.

**Description:**

Outdoor and indoor features must coexist and fluidly transition between the two environments in the same maps and applications used daily in Emergency Operations Centers (EOCs), Public Safety Answering Points (PSAPs), and emergency vehicles.

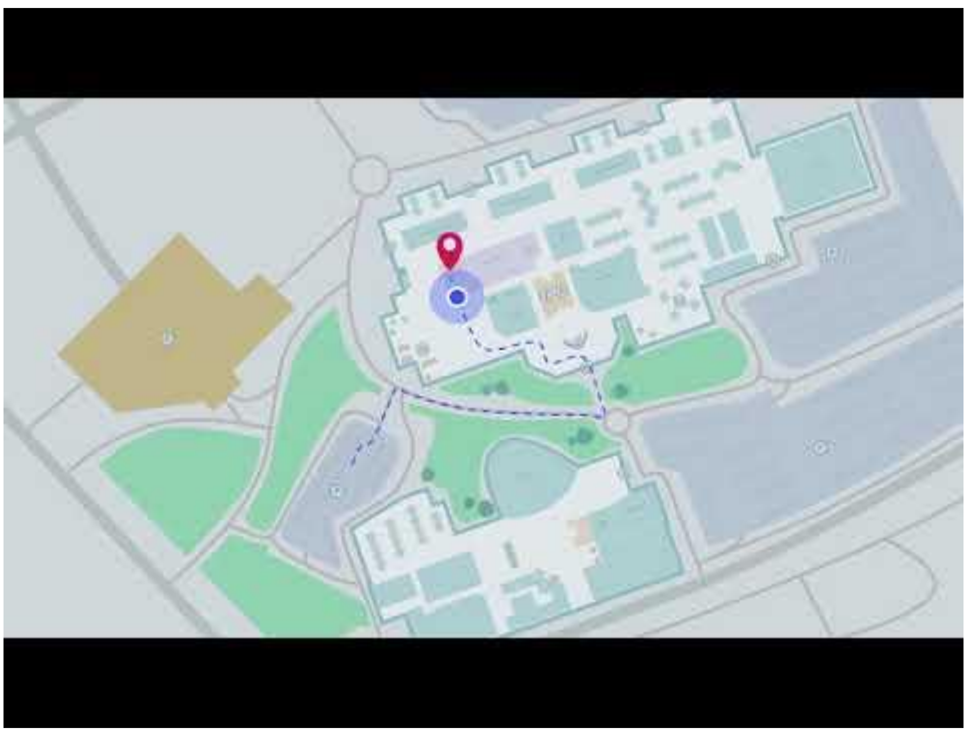


*Figure 8 Inpixon Outdoor to Indoor Transition*

Many first responders have access to maps in their daily routine. These can be in the form of a run book, a CAD map on a Mobile Data Terminal (MDT) or CAD terminal, or a dashboard at an EOC. Some agencies may even have building blueprints and preplans available at a touch of a button. Having a map that seamlessly transitions from the outdoor space to the indoor space is invaluable. The indoor space is considerably smaller than the outdoor environment, so it is important that the map scales properly and can show appropriate features. On multistory buildings, it is important to be able to move from floor to floor to see changes and distinct features on each floor. Viewing the outdoor and indoor environment together gives first responders the whole picture and will allow for safer and more efficient operations.

Outdoor to indoor transition systems should also consider special events and the need to adjust the map and associated routes. For example, a local fairgrounds facility may temporarily convert to host varying types of events, changing ingress and egress routes and relocating offices, command posts, or casualty collection points.

**Further Reading:**

Inpixon Dynamic Outdoor-Indoor Navigation

## 2.5 How to capture 2D and 3D indoor maps

**Statement:**

2D and 3D maps should be created for locations being mapped.

**Description:**

*2D Maps*

2D maps provide location and distance. The 2D mapping process is very mature and has been used in the first responder community for years. Some techniques for capturing 2D indoor maps include:

- CAD drawings
- Building blueprints/as-builts (BIM, Revit)
- Using satellite imagery for building footprints
- GIS-based tools

*3D Maps*

3D maps include the element of height to provide a realistic view of an indoor space. This 3D view can dramatically improve training, pre-planning efforts, and ultimately lead to more effective operations.

A method that is used to create 3D data is light detection and ranging (LiDAR). LiDAR is a remote-sensing technique that uses lasers to measure distances to reflective surfaces and creates a point cloud. LiDAR has seen wide adoption in many fields such as agriculture, Architecture, Engineering, and Construction (AEC), and the military. In public safety, LiDAR is used to recreate crime scenes and for accident reconstruction.

**Further Reading:**

100 Real-World Application of LiDAR Technology

NIST Public Safety Innovation Accelerator Program – Point Cloud City

Microsoft Azure Maps Creator

ArcGIS Indoors

# Case Study:
## City of Memphis MAP901

Through the Public Safety Innovation Accelerator Program – Point Cloud City, the City of Memphis and University of Memphis are working on mapping the indoors of facilities using LiDAR technology. Other technologies in use include $360^{0}$ cameras, temperature, humidity, and acoustic sensors, and inertial measurement units. The purpose of this project is to create rich indoor maps for first responders.

## Data Collection General Best Practices

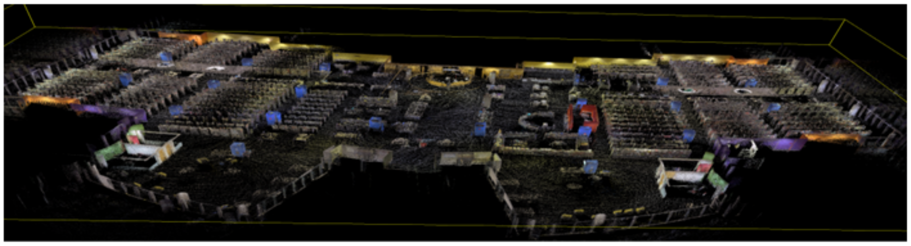
- Objects and/or people should not move around the scene when the 3D scanner is in use.
- The low vertical view of LiDAR sensors tend to miss floors when scanning. Stay 5 feet away from walls or near the center of the room while scanning.
- LiDAR can see through open doors or windows. Reflective surfaces can also impact the end product. Consider covering windows and closing doors before scanning.
- Lighting significantly impacts the quality of the image. Make sure lights are turned on before scanning.
- Most equipment used to create 3D scans use multiple cameras. Avoid getting too close to walls and ensure the cameras have clear views to the scene being scanned.
- Traversing areas being scanned multiple times will improve the end product.

## Data Collection – Simultaneous Localization and Mapping (SLAM)

- 3D scanners estimate their path through the scanned space with SLAM algorithm. The path is critical to putting together the final result.
- If the SLAM algorithm loses track of its path, it will create duplicate images. These errors cannot be corrected in post-processing.
- SLAM algorithms "drift" and become more inaccurate as the scan progresses.
- Different rooms and hallways should be scanned separately as walking through doors can cause SLAM errors.
- Walk at about half the normal walking speed to avoid SLAM errors.

## Data Post-Processing

- To create a complete model of a building, the scans of each room must be registered (joined) together.
- Registering two scans requires at least three common points. More points can improve registration accuracy.
- Consider placing an easy to identify object (like a box) in the scene to ease registration.
- Scanning each room multiple times allows you to select the best quality or easiest to register scan.
- Automatic registration (e.g. iterated closest point) requires at least 50% overlap.



## 2.6 Interoperability

**Statement:**

Indoor mapping products will be interoperable with CAD-based, GIS, and mobile technology applications.

**Description:**

Interoperability should be the cornerstone of any indoor mapping product, process, or technology. Indoor mapping products should be in an easily consumable format and be vendor agnostic. The power of pre-planning comes from the ability to share plans across jurisdictional and disciplinary boundaries with incoming resources. Indoor mapping products should follow a similar process to interoperable communications.

Being interoperable does not mean every agency creates indoor mapping products the same way; instead, interoperability ensures efficient and effective information sharing during incidents. For example, utilizing the Incident Command System or labeling the main entrance of a building Door 1 allows any discipline to communicate.

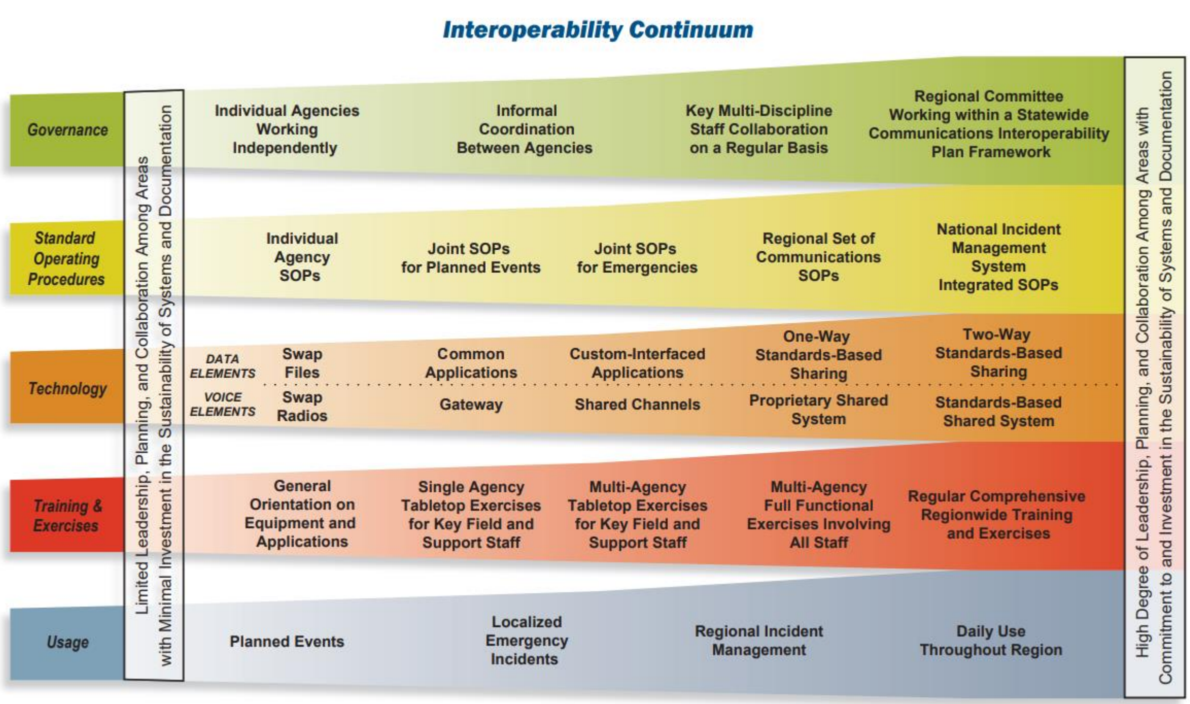



*Figure 9 Interoperability Continuum*

**Further Reading:**

SAFECOM Interoperability Continuum

ArcGIS Data Interoperability

Open Geospatial Consortium

National Information Exchange Model (NIEM)

## 2.7 Equipment

**Statement:**

Hardware for indoor mapping should be as minimally invasive as possible, and software should function on readily available mobile devices.

**Description:**

Indoor mapping technology represents equipment and techniques used to make, analyze, and publish maps. Today the visualization of indoor spaces is presented in both a 2D and 3D map. These best practices represent an evolving technology and will continue to change.

Equipment used to produce and consume mapping products should, at a minimum, do the following:

- Provide sufficient data quality
- Meet minimum accuracy and resolution requirements
- Solve the identified problem
- Avoid prioritizing cost instead of value
- Take into consideration energy consumption

The systems and technology that currently exist include, but are not limited to:

**Systems**

- Hand-drawn blueprints and building drawings
- Computer-Aided Design (CAD)
- Orthographic and satellite imagery
- Simultaneous Localization and Mapping (SLAM)
- Geographic Information Systems (GIS)

**Devices**

- Wearable inertial devices
- Visual odometry
- LiDAR

**Further Reading:**

Simultaneous Localization and Mapping (SLAM): Part I The Essential Algorithms

What is Simultaneous Localization and Mapping?

Visual Odometry (VO)

Inertial Measurement Units

# Tracking

## 3.1 Command and Control Principles

**Statement:**

Command and control principles should be utilized for the tracking of first responders, including who views tracking information and how the tracklogs are displayed.

**Description:**

According to the National Institute for Occupational Safety and Health (NIOSH), many line-of-duty deaths and injuries were a result of the inability to track first responders. In those tragedies, firefighters became disoriented in smoky conditions, were trapped, or had radio failures. The use of a Personal Alert Safety System (PASS) often was not present or was used incorrectly.


*Figure 10 Command Tablet utilizing the Incident Command System (ICS)*

*Principles*:

- The solution does not interfere with existing technology used on emergency scenes.
- The solution provides the Incident Commander the ability to monitor the whereabouts of their first responder crews and is vital for making emergency management decisions.
- The solution can alert the Incident Commander and Safety Officer of potential hazards and identify first responder locations in the event of a Mayday or officer down situation.
- The solution must be both scalable and can integrate into existing technology and policies.
- The solution must share information and maximize productivity, efficiency, and safety.
- The solution must address data and privacy concerns.

**Further Reading:**

Tablet Command Incident Management

ICS Organizational Structure and Elements

## 3.2 Symbology

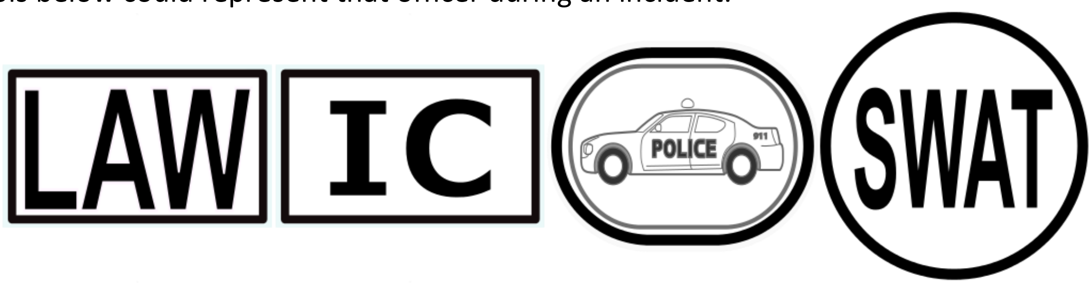
**Statement:**

Symbology used to identify and track personnel and equipment indoors should be consistent with mapping symbology, when applicable. Symbology should be dynamic and represent either individual resources, resource type/kind, or position.

**Description:**

Whereas outdoor mapping symbology typically represents static infrastructure, tracking personnel must be dynamic.

For example, a police officer may be the first responder to a call for service, later assume the role of Incident Commander, or if part of the team, participate in SWAT activities. All four symbols below could represent that officer during an incident.



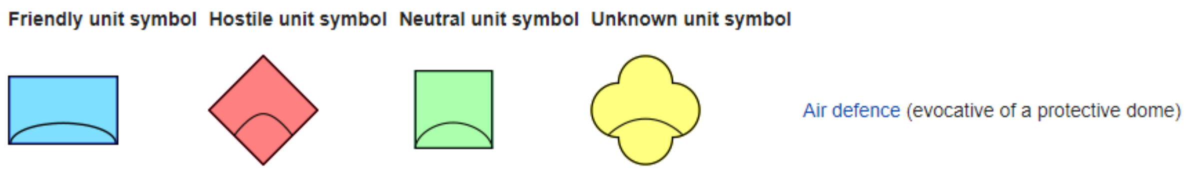

As hundreds of resources pour into critical incidents, it becomes almost impossible to represent individual resources inside of a building; scale becomes extremely important.

*Options for tracking symbology:*

Some options, by discipline, for tracking symbology include:

- Fire: One symbol for an engine with personnel.
- Fire: Unique symbols for specific positions, such as firefighter, engineer, rapid intervention, etc.
- Law Enforcement: One symbol for a SWAT/special vehicle with personnel.
- Law Enforcement: One symbol for specific positions, such as K9, bomb squad, etc.
- EMS: Unique symbols for EMT-B, paramedics, etc.

Personnel tracking symbology has deep roots in military symbol history. These symbols tend to be geometric rather than associative or pictorial to fit in with other military symbol schemas.




Associative symbols are symbols that people typically associate with a specific resource, hazard, or position, but do not actually resemble the actual item. An example may be the EMS symbol.

Pictorial symbols are symbols where the picture shown represents the actual resource. An example may be fire hydrant.

When at all possible, associative or pictorials symbols should be used; these symbols have a much higher recognition rate (Akella, 2009).

Finally, as tracking symbology is developed, consideration should be given on how to convey dynamic status (e.g., heart rate normal = green, heart rate elevated = red).

**Further Reading:**

[NAPSG Symbol Library]

[Joint Military Symbology MIL-STD-2525]

# Case Study:
## Carr Incident
## Glendale Fire, CA

The Carr Incident was a fire that occurred on January 16th, 2020, in the City of Glendale. During this fire, two Glendale Fire Department (GFD) firefighters fell into a basement during an active fire.

This event highlights the challenges faced by firefighters on a daily basis, especially on multi-floor buildings, and stresses the need for improved tracking of first responders.

## Incident Overview:

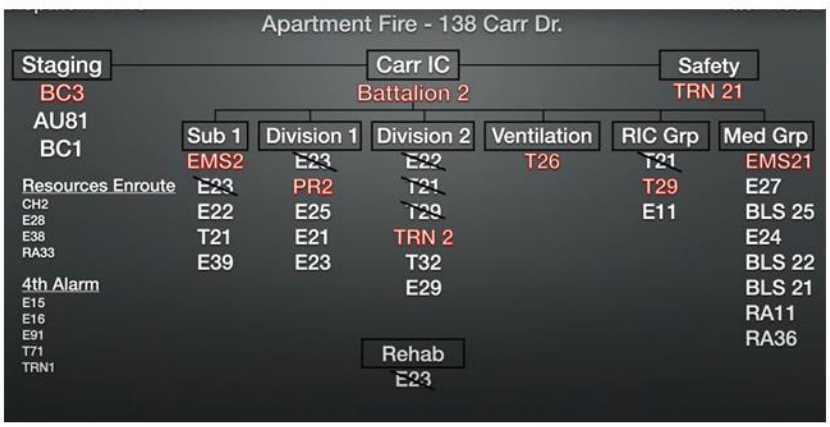
- Structure fire in a 2-story residential building.
- Multiple victims required rescue.
- Rescue and life safety needs prevented an immediate size-up.
- Firefighters on multiple floors: floor 1, floor 2, and ventilation on the roof.
- Identified as a basement fire about 20 minutes after dispatch. Resources on scene attempted to put out the basement fire from the exterior of the building but were unsuccessful.
- While trying to make entry and expedite primary/secondary searches, two firefighters fell into the basement, resulting in a mayday.
- Initially believed to be only one firefighter trapped. Difficulty in relaying information between different units.
- Both firefighters were rescued by the rapid intervention crew (RIC).
- First firefighter rescued in under 1 minute, second firefighter rescued in 3 minutes.

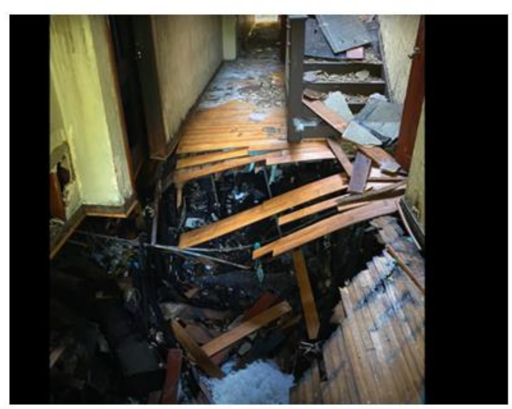
## After Action Review and Lessons Learned:

- Nearly impossible to get a visual in the building because of the smoke, making it hard to identify where the downed firefighters were.
- Include the Thermal Imaging Camera in search operations.
- Use the technology you have on your person: E-Trigger can be utilized if you cannot get through on the radio with emergency traffic.
- Initial confusion on how many firefighters were in trouble highlights the need for personnel accountability.

## How technology can help:

- Tracking firefighters and providing x,y,and z coordinates will allow quicker identification of personnel location, especially during a mayday.
- Utilize the incident command system to ingest mapping, tracking, and navigation data.
- Use symbology to accurately place personnel and teams on a map.
- Use symbology to identify changing roles and positions during an incident (see command structure).



## 3.3 Attributes

**Statement:**

Attributes associated with indoor tracking symbols should include, at a minimum, location, direction, speed of travel, and a unique identifier.

**Description:**

Ideally, the symbology used in indoor tracking conveys more than just a point. Just like fixed assets, personnel attributes can range from very basic information up to incredibly detailed. For example, attributes associated with a firefighter symbol can include:

- Name
- Special equipment
- Oxygen levels (SCBA)
- Temperature
- Call sign
- Time on scene

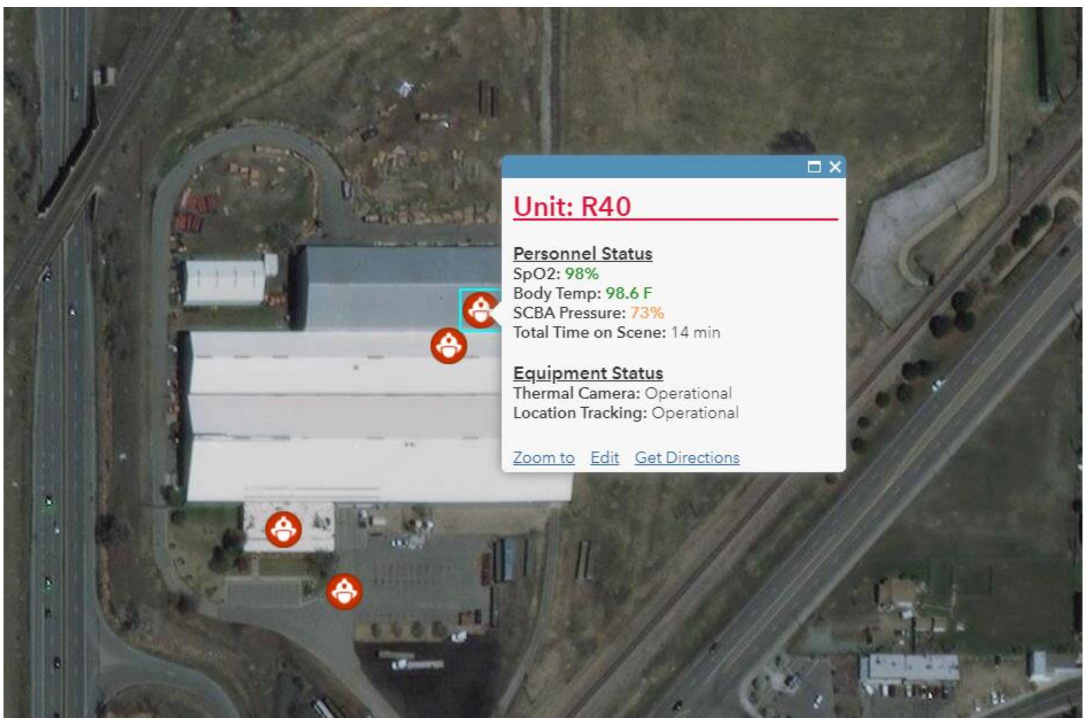



*Figure 11 Attribute Table Pop-Up*

Any number of attributes can be displayed in an attribute table and designed to “pop-up” when selected.

Attribute tables should also consider IoT device data. This data may include type of device, manufacturer, temperature and humidity, connectivity (both strength and which network), and owner.

*Location:*

The attribute table or pop-up should show the location in the same format as was used during the mapping stage. Latitude/longitude and USNG are two options that work well for outdoor environments and may be used indoors. Additionally, if building information modeling is available, these locations may be converted into floors, office numbers, common spaces, or other locations inside of a building.

*Direction:*

For symbols with a directional quality (e.g., arrows or the front of a vehicle), directionality can be easily determined. For symbols without a directional quality (e.g., a single firefighter) a method to determine the directionality, such as an azimuth, should be provided.

*Speed of travel:*

Reporting of speed is dependent on the equipment on the first responder. When possible, display speeds in a similar manner to that of equipment (e.g., miles per hour).

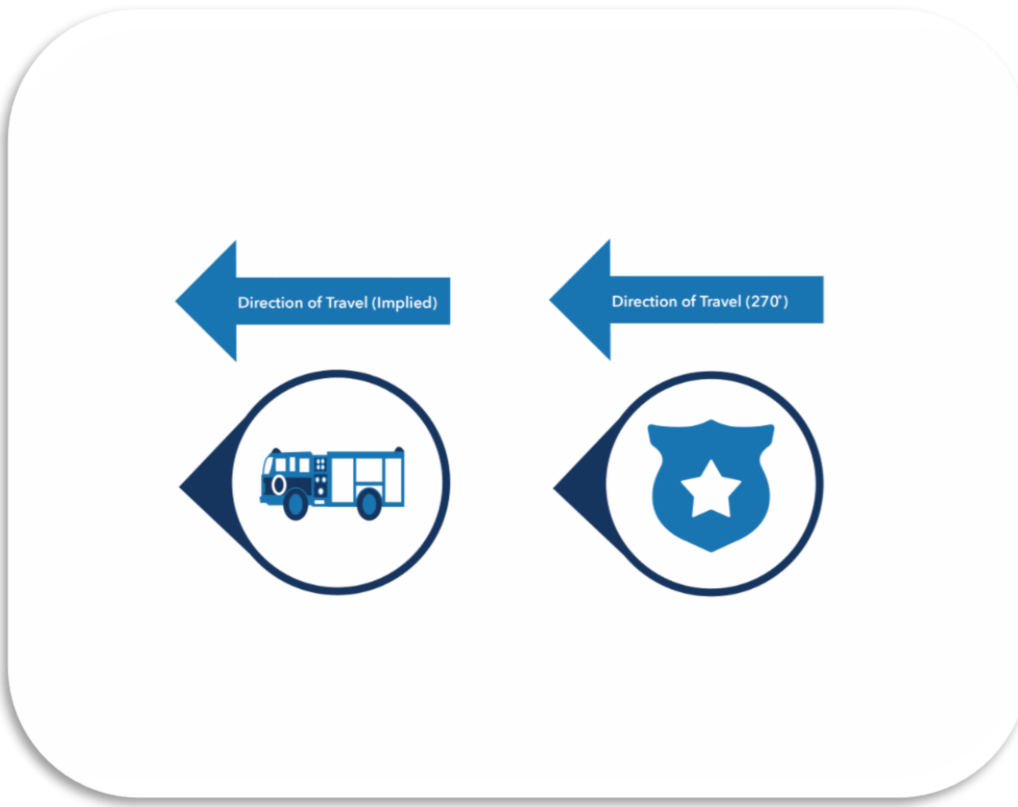



*Figure 12 Directionality representation*

*Unique identifier:*

Unique identifiers allow the incident commander or other public safety personnel to easily identify specific people. Unique identifiers are ubiquitous in computer-aided dispatch systems but require prior knowledge to decipher the meaning.

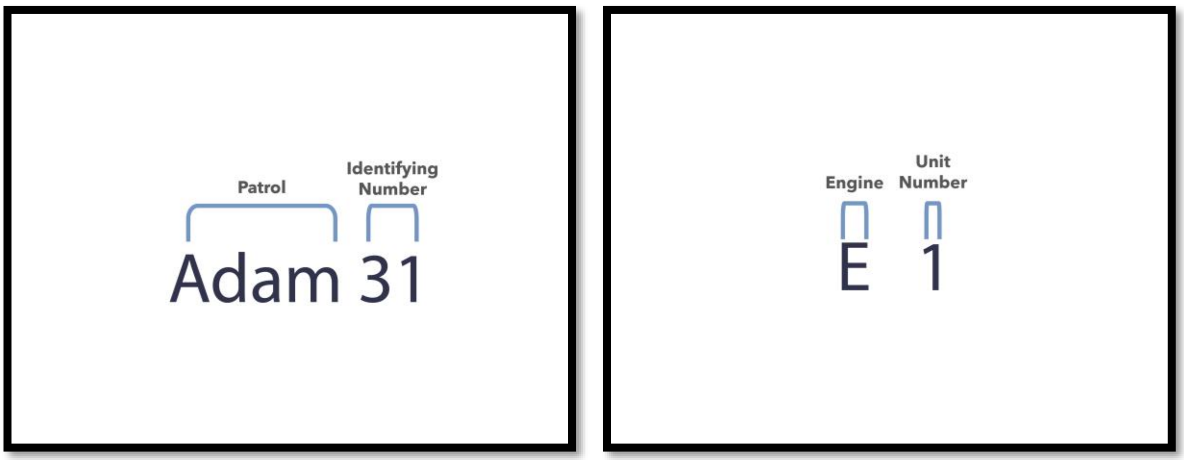



*Figure 13 Call-sign example*

Although call-signs are effective internal to single agencies, when working with mutual aid partners, confusion often occurs. If non-traditional response partners such as utilities, the private sector, or volunteer agencies are on scene, they will not have preidentified call-signs. There may also be multiple "Engine 1" or other resource identifiers when neighboring agencies respond to a mutual aid event.

When representing resources geospatially, agencies should utilize their internal naming system and pick a unique identifier that is directly tied to a single person, not a specific role.

**Further Reading:**

[Seattle Police Department Manual, Communications]

## 3.4 Coordinates, Accuracy, Precision

**Statement:**

Three-dimensional (x,y,z) coordinates should be collected for personnel tracking. Coordinates for tracking personnel indoors should provide a high enough level of accuracy to identify both floor level and approximate location in a building.

**Description:**

Unlike indoor mapping, tracking of personnel is dynamic and suffers from the real-time requirement for accurate coordinates. Common issues such as connectivity and inertial sensor drift tend to make tracking responders indoors difficult. Coupled with the lack of indoor positioning systems in most buildings, responders will have to bring the tracking system with them to a call (for now).

Traditionally, tracking equipment to improve the accuracy and precision of responders is bulky, reliant on battery packs, and specific to certain vendors. The different types of equipment available is expanded in the equipment section.

The best practices in the mapping section hold true when tracking personnel.

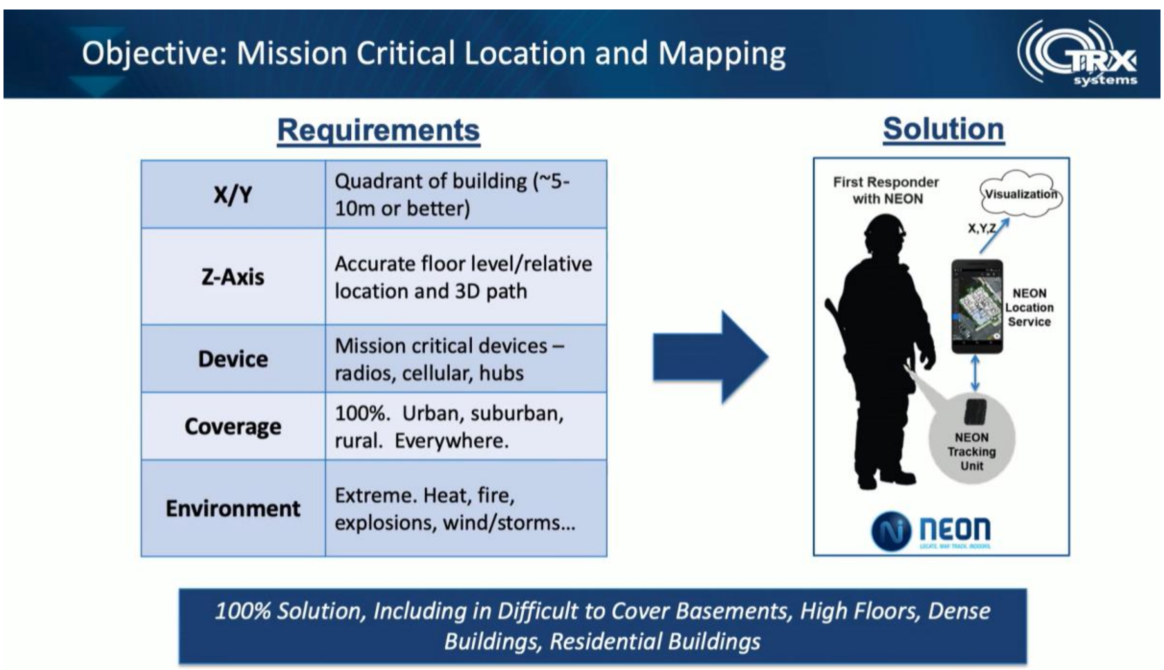



*Figure 14 TRX Tracking Requirements*

**Further Reading:**

TRX Systems

3am Innovations

## 3.5 Interval

**Statement:**

Refresh intervals for personnel tracking should be as frequent as possible, but no longer than 1 minute during an emergency.

**Description:**

Tracking interval indicates the time or distance traveled that has passed between each instance of a device capturing and sending its location. Tracking of vehicles in public safety is common today, and most departments use GPS to locate and dispatch units on calls. When setting the interval of the devices, it is imperative to test the system and know its limitations.

Time and distance are the common intervals used today. Other considerations for public safety in tracking personnel are height above ground level, environment, biometrics, and mayday events. These public safety specific intervals could also set the system into alarm mode and notify other first responders of a life-threatening situation. Intervals could be set to change if a first responder falls from a ladder or down an elevator shaft. If environmental conditions change or certain biometric thresholds are passed, an interval could be set to report more frequently. Finally, if a mayday is called by the first responder, the device could switch to a new interval so rescuers can know exactly where the endangered first responder is located.

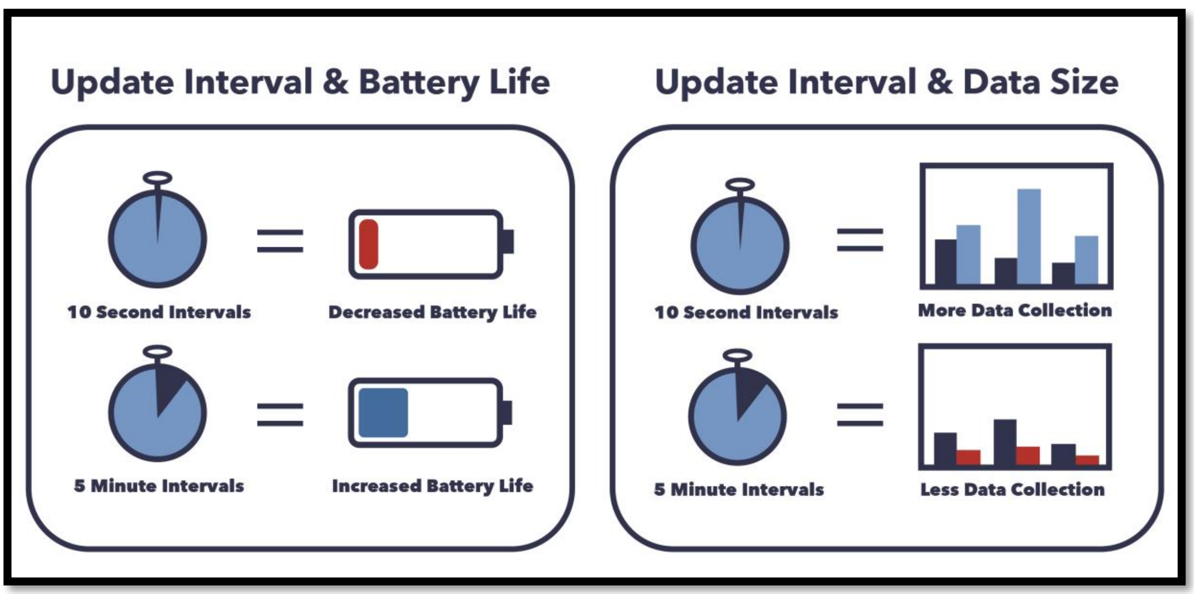



*Figure 15 Interval, battery life, and data storage*

Battery life and data storage are additional considerations when setting up interval reporting windows. A shorter tracking interval means that the device records and reports more frequently. This leads to more data being collected and a shorter battery life for the device. It is crucial to test your devices with different configurations to understand how long a device can last on a single charge.

**Further Reading:**

GPS Tracking: The balance between tracking intervals and battery life

Optimize location for battery, Android

## 3.6 Last Known Point (LKP) vs. Tracklogs

**Statement:**

Tracking information and systems should include both last known point and tracklog information.

**Description:**

Last known points typically convey a single point in time. LKP is important when locating casualties or mayday/officer down calls.

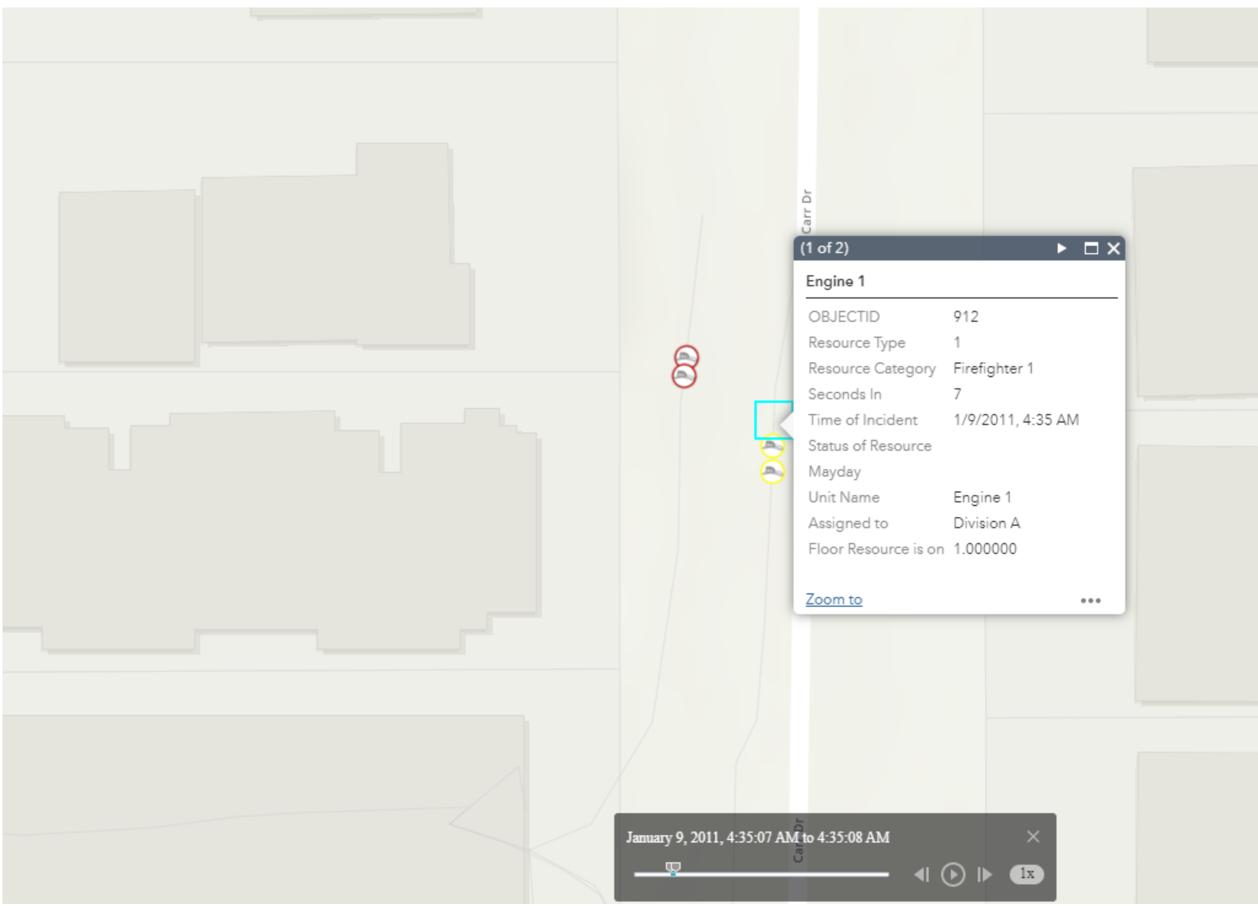



*Figure 16 Last known point example*

The example above shows a time-enabled response to a fire call. When showing individual resources, the attribute table will show identifying information on top of the current time, time into the response, and any status or mayday calls. Based on the latency of sending location information, the resource should be at or around the position shown on the map.

Tracklogs show where a specific resource or person has been over time. Tracklogs are important during building clearance operations, decontamination, explosive ordinance disposal, and any other situation that requires historical information. Tracklogs can also be used for after-action reviews and to identify resource movement.

Tracklogs and reporting intervals can also be dynamic. In a steady state, reporting intervals can be set at a constant time (e.g., 30 seconds), whereas in an emergency such as an officer down scenario the interval may change to every 10 seconds. As biometric devices become more common, dynamic reporting intervals will become an important design choice.


*Figure 17 Tracklog example*

**Further Reading:**

[Collecting Field Data]()

## 3.7 Outdoor to Indoor Transition

**Statement:**

Tracking of personnel should have a seamless outdoor to indoor transition. A first responder should be able to enter and exit a structure with little to no interruption of signal. Additionally, tracking personnel should be infrastructure-free, meaning that there should be no expectation of tracking equipment inside of a building.

**Description:**

The majority of infrastructure does not have indoor positioning equipment, and many even lack basic connectivity (Wi-Fi, WAPs, etc.). In this scenario, a responding agency needs to deploy its own tracking system. This system needs to be deployable quickly, connections need to be instant, and the transition from outdoor to indoor needs to be seamless. Some challenges around deploying indoor positioning systems (IPS) include:

- Initial setup of equipment during time-sensitive response
- If necessary, deploying “nodes” to extend in-building coverage
- If in use, overcoming inertial sensor drift
- Data feeds and consumption – Who views this information?

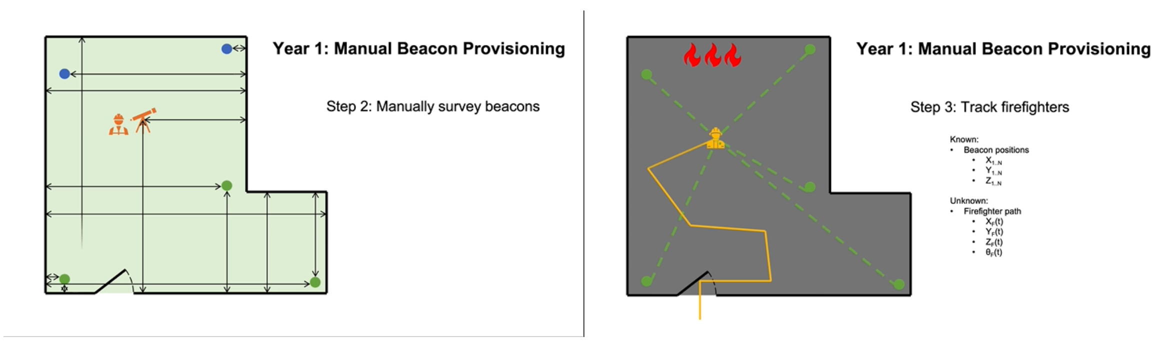



*Figure 18 Beacon Provisioning, Anthony Rowe, Carnegie Mellon University 2020*

The example above shows different versions of manual beacon provisioning to track responders indoors. In the first image, manual beacons are placed and then a true survey methodology is followed. This provides a very accurate measurement but is very time consuming. In the second image, manual beacons are still placed, but the system automatically measures based on the location of the responder. Both workflows require responders to visit the location before an incident to ensure a proper outdoor to indoor transition.

For smart or connected buildings, there are information sources public safety needs to consume. IoT devices such as security cameras, thermostats, occupancy sensors, and smart locks can all provide critical information or access to facilities. These connections will provide valuable information about the infrastructure, but currently do not necessarily help with the tracking indoors.

**GPS Location**

Sample Data Object

| INDEXES | SHORT FORM | GLOBAL? | UNITS | REQUIRED | FORMAT | OOBNV |
|---|---|---|---|---|---|---|
| Latitude | lt | Global | Degrees | ✓ | 36.089 | 999 |
| Longitude | lg | Global | Degrees | ✓ | -79.162123 | 999 |
| Altitude | lz | Global | MSL | ○ | 182 | -999 |
| Speed | ls | | M/S | ○ | 22.35 | -1 |
| Speedmph | lm | | Miles/Hr | ○ | 50 | -1 |
| Heading | lh | Global | Degrees | ○ | 359 | -1 |
| Accuracy | la | Global | Meters | ○ | 4 | -1 |
| Numsats | lns | | Integer | ○ | 7 | -1 |
| Timestamp | ts | | Seconds | ○ | 1596014568 | -2 |
| Source | src | | <string> | ○ | "GPS" or "WiFi" | "" |

12

*Figure 19 IoT Sample Data Object*

The GPS Location example above shows some of the different information that may be provided by an IoT device. Determining which pieces of information public safety needs and how to display in an attribute table are important.

As we move into a more connected environment, knowing the structures and facilities that have a tracking network will be important. Having a GIS layer in the CAD system and making it available to dispatchers and first responders to visualize connected structures will become a necessary operational layer.

**Further Reading:**

What is IoT? How Smart Building Technology is Changing Facilities Management - [https://www.buildings.com/news/industry-news/articleid/21603/title/iot-smart-building-technology](https://www.buildings.com/news/industry-news/articleid/21603/title/iot-smart-building-technology)

## 3.8 Equipment

**Statement:**

Systems and technology used for tracking are critical to safety across a whole community and should be as minimally invasive as possible.

**Description:**

Equipment for first responders should try to provide location intelligence and/or spatial intelligence. This is the process of deriving meaningful insight through relationships of geospatial data to track a responder and requires the layering of multiple data sets spatially and/or chronologically for easy reference on a map.

There is also a strategic question around equipping responders with the tracking equipment or installing tracking equipment inside a building. In this guide, we include equipment from both categories. Some mature and emerging fields and technologies that may help facilitate responder tracking includes:

- AI Deep Learning Vision
  - Vision Analytics works by recognizing patterns in images
- Biometrics - Facial Recognition
  - Facial Identification: the technology compares an image to a given image within a database. Facial Identification is often used for security and surveillance.
  - Facial Selfies: the same technology as facial identification with one caveat – the person uploads their own image, tags it, and consents to sharing the data. Used in loyalty programs.
  - Facial Demographics: the software processes facial features and provides an output that includes gender and age. The identity of the face remains anonymous.
- Biometrics - Eye Tracking
  - Measures the relative motion of the eye to the position of the head
- 3D Spatial Learning (Augmented Reality)
  - Adding images, sounds, and text to what is currently in place in the real world

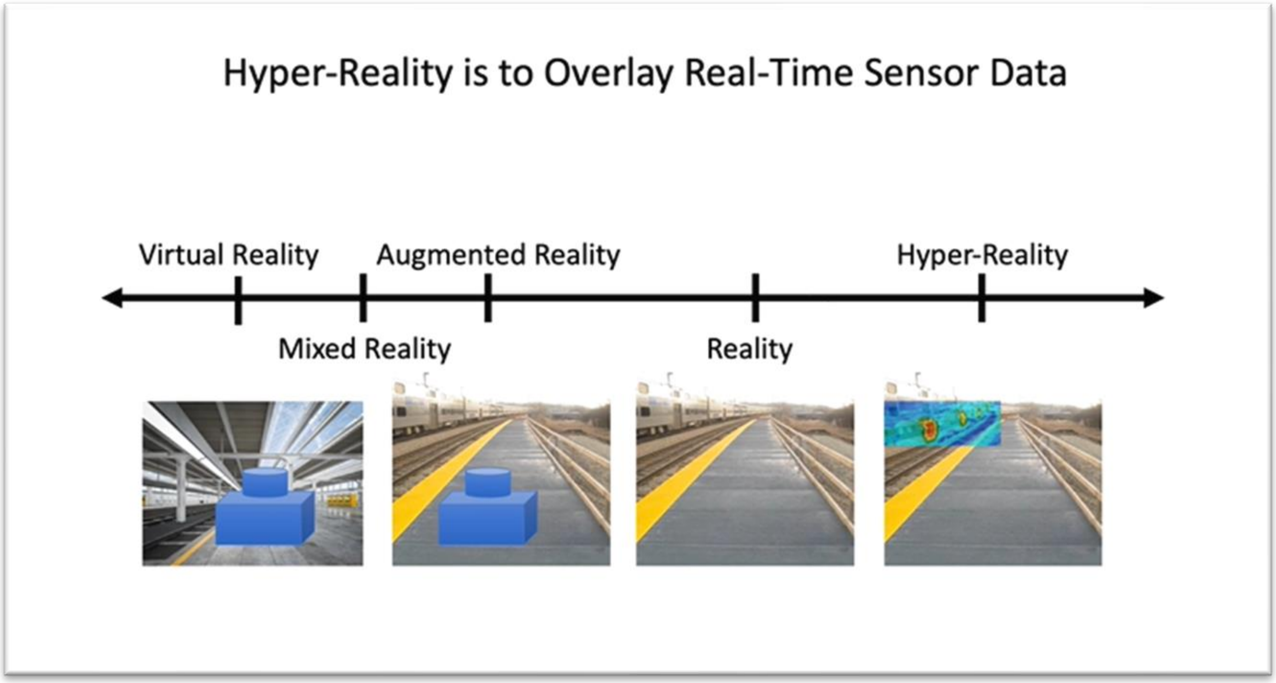



*Figure 20 Hyper-Reality graphic, Yang Cai, Carnegie Mellon University 2020*

- 3D Stereo Video Analytics
  - Stereo video sensors are designed for tracking objects across the camera's Field of View and is made up of a high-resolution camera and processor for the three-dimensional capture of the object. The 3D architecture compensates for occlusion and shadows by adding depth (distance from the camera).
- 2D Monocular & Fisheye Video Analytics
  - Images are captured through the camera and processed within the analytics
  - Thermal Imaging
  - The collection of emissions from moving objects
- Time of Flight (ToF)
  - Detecting the time of light between the camera and the object using a laser beam.
- Structured Light 3D Scanner
  - An array of lights strikes the surface with a known pattern and calculates the depth and surface of objects.
- LiDAR 3D Laser Scanning
  - Deploying a scanning technology that sends laser and measures the return times and wavelengths to create a three-dimension visualization of the targeted object.

- Open-Source Raspberry Pi
    - Open-Source hardware that may serve as a component to a tracking device
- Wireless Access Points (WAP)
- UWB (Ultra-Wide Band) Ranging
    - Functions in low-energy, short-range, and high-bandwidth environments. UWB Ranging uses radio waves at high frequency to continuously scan objects and report the location.
- BLE (Bluetooth Low Energy) Beacons
    - Beacons historically have been for tracking (opt-in) loyalty customers in physical locations.
- GPS (Global Positioning System) Personal Trackers
    - GPS is built into the operating platforms of devices, and therefore the tracking technology provides real-time and historical data on the customer's journey.
- RFID (Radio Frequency Identification) Tags & Tracking
    - RFID uses electromagnetic fields for tracking

Current technology and devices may also be integrated with newer mapping, tracking, and navigation systems.

- Land Mobile Radio (LMR) devices
- Personal Alert Safety System (PASS)
- Mobile Data Terminals (MDTs)
- FirstNet approved devices

**Further Reading:**

Hyper-Reality Helmet Technology

# Navigation

## 4.1 Symbology

**Statement:**

Navigation symbology, whether 2D or 3D, should match the symbology used for mapping and tracking. Navigation symbology should also use common color ramps to indicate route quality.

**Description:**

Consistent symbology is critical to understanding how to navigate to or around a location, barrier, or impedance. Outdoor navigation best practices apply indoors, including common color ramps.

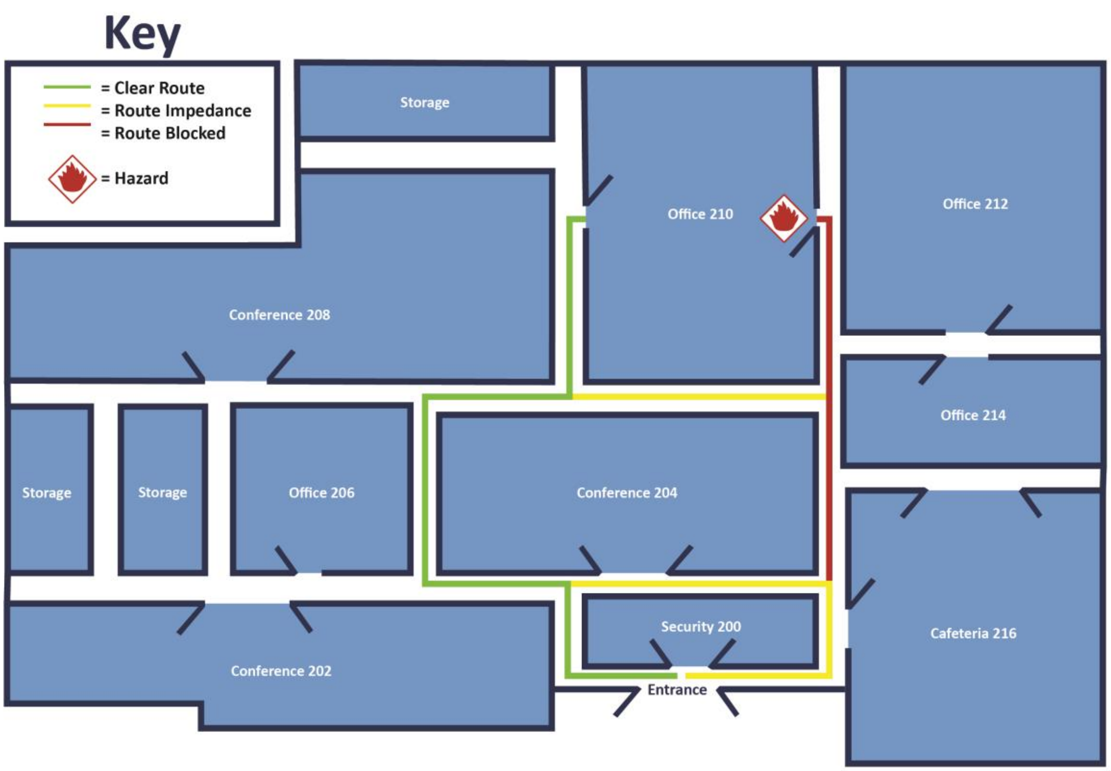



*Figure 21 Indoor navigation color ramp example*

Some challenges when addressing navigation symbology include:

- Symbolizing hazards: In augmented reality/virtual reality (AR/VR), we can display hazards such as fire location, casualties, hazardous material, or other mobility hazards to responders. Placing these symbols in real time as a responder moves throughout an incident is the goal.
- How 3D objects are displayed: It is the vendor responsibility to determine how symbols are displayed, either on a heads-up-display (HUD) or a screen for external personnel to direct the responder. Either way, there are unique challenges to symbolizing 3D objects indoors.
    - How are floors displayed?
    - Are walls displayed as a line, or extruded to a full 3D wall?
    - Are arrows shown along the route to direct the responder, or just all available paths?

**Further Reading:**

Indoor Mapping Data Format (IMDF)

# Case Study: Carnegie Mellon University

Through the Public Safety Innovation Accelerator Program – Location-Based Services, the Carnegie Mellon University team is designing a hyper-reality helmet to provide on-demand information on a heads-up display for first responders. This helmet is dependent on pre-incident planning and mapping and sensor integration.

## Project Overview

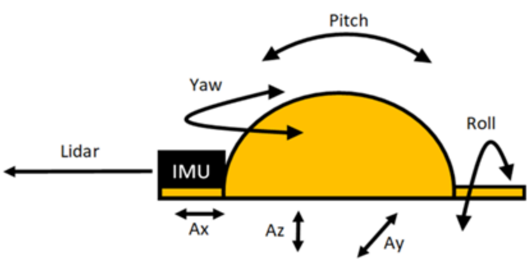
- Rapid prototyping of the holographic display and data processing helmet.
- Landmark recognition and tracking for correcting accumulated mapping errors and tagging landmarks on the map.
- Indoor navigation with sensor fusion and human-machine interaction
- Gesture and speech recognition for navigating and information retrieval.
- Superimposing live thermal images and contours.
- Human-robot interaction interface with live drone video streaming.

## Sensor Integration

- Thermal Imaging Sensor
- Distance Sensor
- Depth Sensor
- Inertial Measurement Unit (IMU)

## Imaging and Navigation

- Moving the head/helmet side to side creates accurate images in a 2D/3D space.
- Real-time images can be shown on a heads-up display for navigation or scan coverage confirmation.
- Accuracy of the helmet for horizontal and vertical profiling can achieve an accuracy of ±3 cm.




## Data Post-Processing

| Output Class \ Actual Class | Crawl | Downstair | Duckwalk | Run | Stand | Upstair | Walk |
|---|---|---|---|---|---|---|---|
| Crawl | 90.8% | 0.0% | 3.9% | 0.0% | 0.0% | 0.0% | 0.0% |
| Downstair | 5.0% | 83.6% | 0.0% | 0.6% | 0.0% | 8.0% | 0.8% |
| Duckwalk | 0.0% | 0.0% | 80.6% | 0.0% | 0.0% | 2.3% | 0.0% |
| Run | 0.0% | 0.0% | 0.0% | 93.6% | 0.0% | 0.0% | 0.0% |
| Stand | 0.0% | 0.0% | 0.0% | 0.0% | 91.4% | 0.0% | 0.0% |
| Upstair | 3.3% | 15.8% | 2.9% | 5.8% | 5.9% | 81.7% | 13.9% |
| Walk | 0.8% | 0.6% | 12.6% | 0.0% | 2.6% | 8.0% | 85.2% |

Overall Accuracy: 86.6%

- Decision tree model can predict 7 different activities.
- The learning algorithm can be expanded with new sensors or new activity training data.

## 4.2 Wayfinding, Routing, Barriers

**Statement:**

Technology supporting wayfinding by first responders should include dynamic routing and barrier identification. Navigation indoors should be an extension, and when at all possible, similar to the methods of response in a vehicle.

**Description:**

*Wayfinding and routing:*

Effective wayfinding is critical for first responders. Despite a comprehensive understanding of the jurisdictions in which these personnel operate, most responders have never been to the facility they respond to. A study by MIT (Foltz, 1998) finds that effective wayfinding requires:

- Identities for each location
- The use of landmarks (e.g., the flagpole)
- Structured paths (emphasizing line geometry)
- Limited choices in navigation
- Signage
- Utilizing sight lines to show what is ahead

Fire and law enforcement personnel way find differently on most calls for service, and they use different senses. Law enforcement typically responds to and moves towards stimulus, utilizing sounds (screaming, gunshots), smells (gunshot/cordite smell), and visual cues such as fleeing civilians. Fire personnel are more methodical in their approach, relying on visual cues (smoke, fire) and sounds (fire alarms) to move towards an incident. This results in very different wayfinding approaches, necessitating a technology that can route first responders depending on incident type and discipline. Concerns when routing first responders include:

- Responder equipment: Firefighters must drag fire hoses through a building, wear SCBA's, and in general have a larger profile based on standard equipment.
- Incident type: In an active threat scenario, law enforcement should be routed by fastest route. In a fire scenario, responders should be routed by safest route.
- Building type: Residential, commercial, industrial, and campus-style buildings each present unique challenges based on naming conventions, accessibility, and general size.

*Barriers vs impedances:*

Barriers and impedances impact the ideal route for first responders. Barriers typically block movement and require substantial responder intervention to overcome. Examples of barriers include walls, roofs, or heavy debris requiring specialized equipment to overcome. Impedances reduce the speed of operations by presenting something in the way of the ideal route. Examples of impedances include locked doors, disabled elevators, furniture, clutter, or incident hazards such as explosives or hazardous materials.

*Unique challenges to public safety:*

Routing should consider the unique operational environment of first responders. The following topics address core needs during life safety activities:

- Dynamic routing: Dynamic routing should consider direct observations (radio traffic regarding a barrier) and indirect observations (tracking personnel going down an alternate hallway). This can be enhanced with the use of AI for self-reporting.
- Routing based on resource size: Vehicle routing already considers resource size. For example, turns or streets that may not accommodate a fire engine are included in the routing database. Routing personnel in a building should also consider equipment size, whether that is traditional law enforcement, fire, or EMS equipment, or specialized equipment such as explosive robots.
- Risk methodology: Another option to consider is a risk methodology for routing. For example, if a responder encounters a barrier (wall), and the construction materials are known (drywall), a calculation can be made to determine if going through the barrier is more efficient than going around a barrier.

**Further Reading:**

Vertical and Indoor 9-1-1 Location Mapping

## 4.3 Outdoor to Indoor Transition

**Statement:**

Navigation for first responders should have a seamless outdoor to indoor transition. Outdoor and indoor navigation systems utilize different technologies and equipment; however, the visualization for the first responder should remain constant.

**Description:**

Outdoor navigation is one of the more mature applications in public safety. Whether it is using a propriety system integrated with CAD systems, or publicly available solutions such as Google Maps or Apple Maps, outdoor navigation technologies consider route speed, road closures or slowdowns, vehicle size, pedestrian-only areas, and other unique items such as tollways.

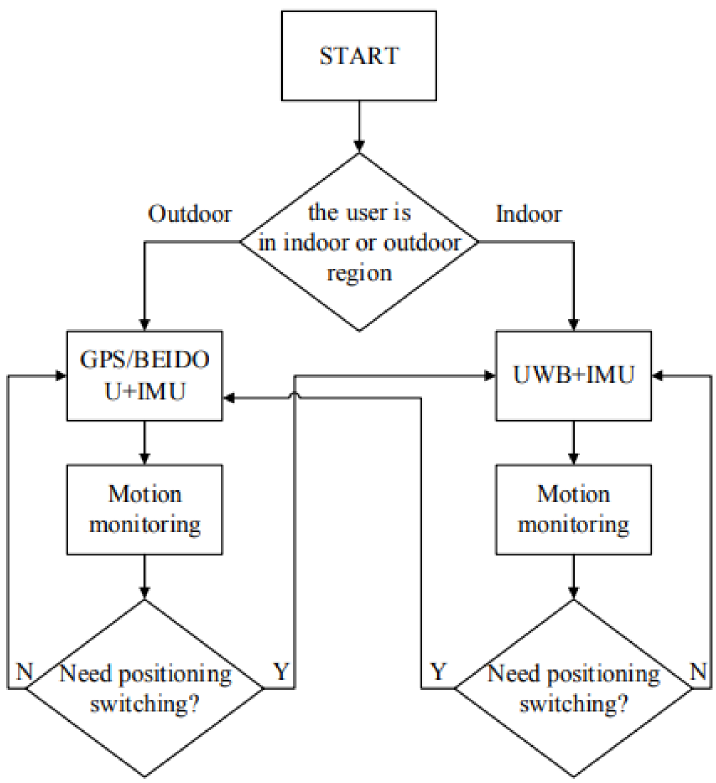



*Figure 22 Example architecture of outdoor/indoor system*

Although advancements have been made in the use of ultra-wide band and low-frequency magneto-quasistatic fields for navigation indoors, they still suffer from challenges such as:

- Battery life
- Equipment size
- Building penetration
- Signal interference
- The requirement for indoor infrastructure

Additionally, the schemas used to assist in outdoor to indoor navigation should consider Next Generation 911 systems.

Indoor navigation also requires a higher level of accuracy than traditional outdoor navigation systems. A final consideration is the ability of a device to recognize whether the responder is in a vehicle (mounted) or on foot (dismounted).

**Further Reading:**

Combining Indoor and Outdoor Navigation: The Current Approach of Route Planners

HERE Indoor Positioning

## 4.4 Equipment

**Statement:**

Indoor navigation equipment should provide the same user experience, visuals, and symbology as outdoor navigation equipment. If possible, navigation equipment should be interoperable with both wearable technologies and infrastructure already in place.

**Description:**

Indoor navigation has typically been used as a tool for businesses, large venues, or special event planners to route customers and attendees to their location. Locations such as airports, malls, stadiums, and transit stations have a safety incentive to route the public to where they are trying to go, a tenet of the Crime Prevention Through Environmental Design (CPTED) process.

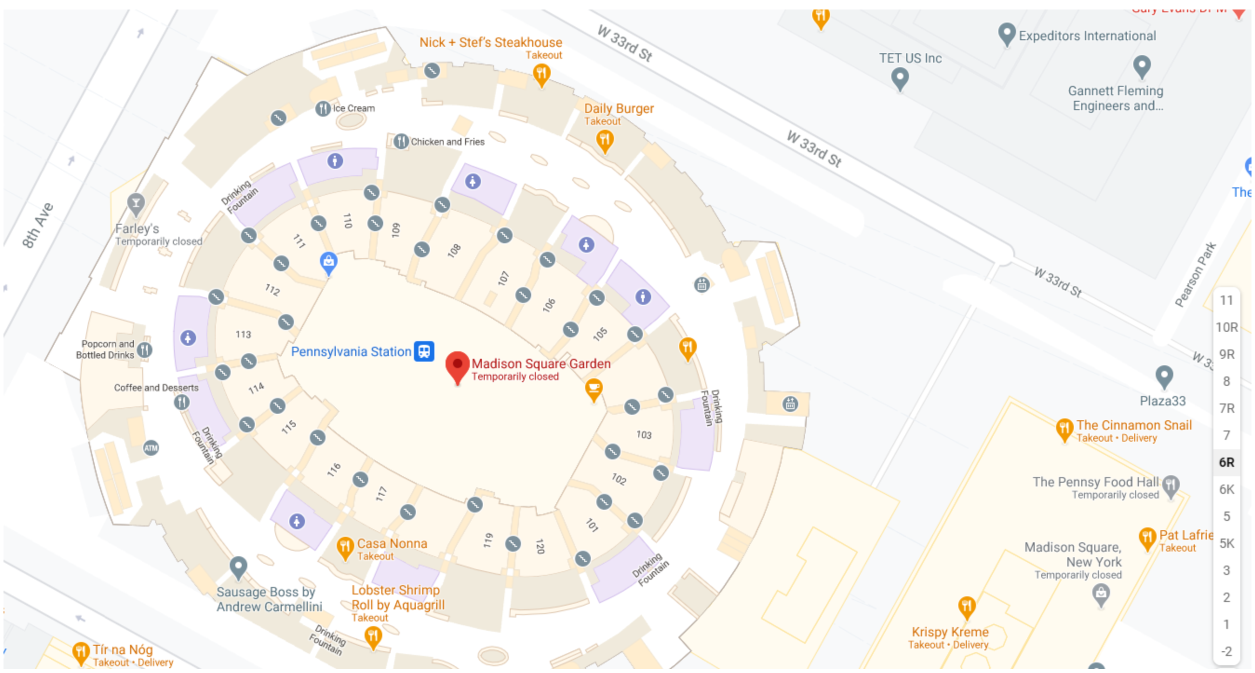



*Figure 23 Google Indoor Maps example*

For responders, navigating to the correct entrance, floor, or location is critical. Figure 23 shows an example of Madison Square Garden. On the right side of the map, a floor selector allows a user to pick a floor, suite, or restaurant.

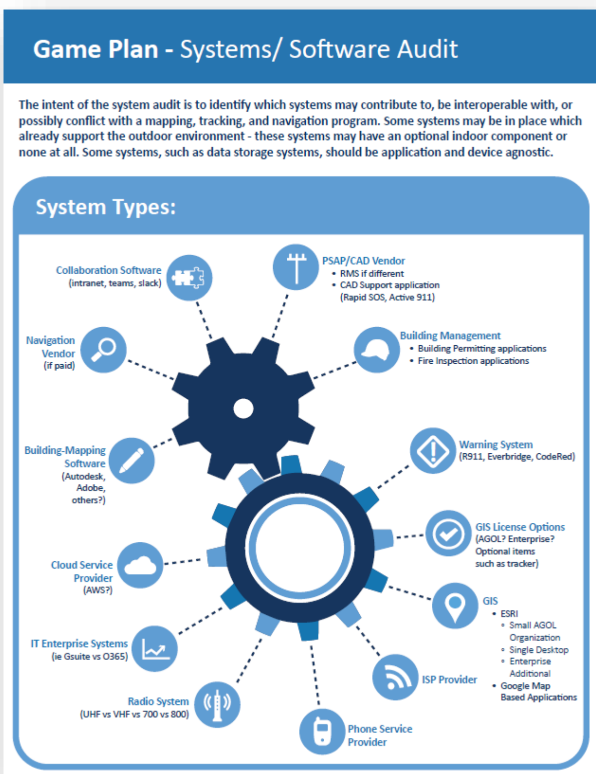
**Further Reading:**
[Google Maps: Indoor Maps]

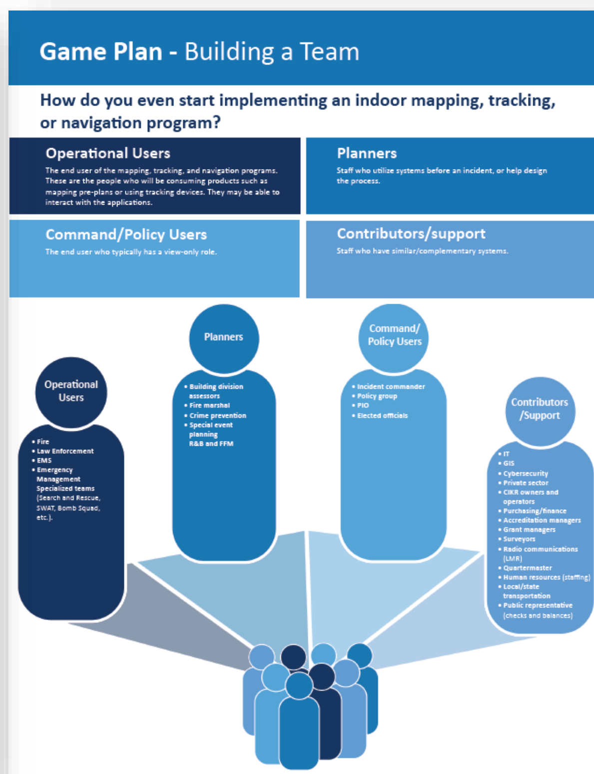
# Game Plan

**Coming in Version 2:**

This section will provide a game plan to assist agencies in developing an indoor mapping, tracking, or navigation program. Topics to be addressed include:

- Building out a multidisciplinary team.
- Conducting a system and software audit.
- Conduct a device audit.
- Common mapping approaches.
- Common tracking approaches.
- Common navigation approaches.
- Governance and policy concerns.
- Project management approaches.
- Common procurement and funding questions.



## Glossary

AVL – Automatic vehicle location
CAD – Computer Aided Drawing
CAD – Computer Aided Dispatch
EOC – Emergency Operations Center
Esri – Environmental Systems Research Institute
FCC – Federal Communications Commission
GIS – Geographic Information Systems
i-Axis – Information axis
IoT – Internet of Things
IPS – Indoor Positioning Systems
LBS – Location-Based Services
LiDAR – Light detection and ranging
MDT – Mobile Data Terminal
NAPSG – National Alliance for Public Safety GIS Foundation
NIOSH – National Institute for Occupational Safety and Health
NIST – National Institute of Standards and Technology
PASS – Personal Alert Safety System
PSAP – Public Safety Answering Point
PSCR – Public Safety Communications Research

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